

INTERMODAL TRAIN LOADING METHODS AND THEIR EFFECT ON INTERMODAL TERMINAL OPERATIONS

BY

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THESIS

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ABSTRACT

The second largest source of revenue for North American railroads is the transport of intermodal freight. In comparison to truck transport, railway intermodal transport is more efficient due to the low-friction interface between the steel wheel and steel rail, closely coupled railcars, rolling stock capable of transporting multiple trailers and/or containers on a single railcar, and the ability to form long trains operated by a small number of operating personnel.

In spite of its energy efficiency relative to trucks, rail intermodal freight has a higher fuel consumption rate than railroad bulk freight. This is due to its greater aerodynamic drag and the higher operating speeds that are required to compete with trucks. In 2008, Class I railroads spent \$12.2 billion on fuel, representing 25.8% of their total operating expense. Maximizing the use of railcar wells and platforms and minimizing gap lengths between containers and/or trailers improves asset use as well as fuel efficiency by reducing aerodynamic drag.

In this thesis, I summarized the physical and operational components of an intermodal terminal and how to measure an intermodal terminal's performance. I reviewed how North American railroads measure intermodal train loading and discussed how loading performance is affected by terminal operations. I described how a machine vision system developed by the University of Illinois at Urbana-Champaign evaluates intermodal train energy efficiency based on the container/trailer loading arrangement and the type of rolling stock used. I analyzed terminal loading data and demonstrated how it can be used to evaluate loading performance and specific processes within a terminal. This research investigated how railroads can reduce intermodal train fuel consumption through improved loading practices while minimizing negative impacts to terminal performance.

*Dedicated to my Deliverer: “Though an army besiege me, my heart will not fear. Though war
break out against me, even then I will be confident” (Psalm 27:3)*

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CHAPTER 1: INTRODUCTION

1.1. OVERVIEW OF INTERMODALISM AND CONTAINERIZATION

Intermodal freight transportation has been defined as the "coordinated door-to-door delivery of freight using two or more modes of transportation" (Chatterjee and Lakshmanan 2008). Intermodal freight is transported in containers or trailers by train, truck, or containership (Figure 1.1). The steady increase in intermodal freight traffic volume in the United States is attributed to freight customers shifting from mode-based to performance-based transportation logistics goals, the emergence of innovative supporting technologies (computers in the 1970s, rail intermodal rolling stock in the 1970s and 1980s, etc.), and increased highway congestion (Chatterjee and Lakshmanan 2008). Its success is also due to the successful integration of intermodalism and containerization that had not been successfully combined in the past. This merger lowered transportation costs while maximizing the operational efficiency of all utilized modes.



(a)



(b)



(c)



(d)

Figure 1.1 (a) Double-stacked intermodal containers in a well car (Graham 2004), (b) intermodal trailer on a spine car (Fuhrman 1986), (c) intermodal containers on a containership (Ports and Ships 2008), and (d) intermodal container on a truck (Schneider intermodal truck nd)

1.1.1 Intermodalism

Intermodalism maximizes “transportation efficiency by exploiting the comparative advantage of each of the modes in handling different types of freight movements”

(Transportation Research Board 1992). An early application of intermodalism was the use of rafts, ferries, and/or barges to move horse-drawn carriages across bodies of water (Mahoney 1985). For example, barges on the Pennsylvania Canal provided intercity transport of passengers and freight from wagons, railroads, and other canals between Philadelphia and Pittsburgh (Mahoney 1985). Other early applications of intermodalism occurred on railroads; the Union

Pacific Railroad transported Conestoga wagons in Oregon during the 1880s and the Long Island Railroad transported farmers with their livestock, produce, and wagons to New York City in the late 1880s and 1890s (Woods and Johnson 1996, Armstrong 2008). The earliest known example of a railroad hauling motor vehicles was in 1926, when the Chicago, North Shore and Milwaukee Railroad began transporting truck trailers on flatcars (Mahoney 1985). This service, which came to be known as “piggyback” service, increased slowly but steadily until the 1950s when it began to grow more rapidly.

Early applications of intermodalism demonstrated that shipping truck trailers on railcars could be more competitive than single-mode freight transportation (Mahoney 1985). The railroad transports the trailer over a large portion of the distance at lower cost while a truck handles local or regional pick up and delivery to shipper and/or customer facilities. Despite their advantages, the efficiency of these early intermodal applications was limited by the rate and expense of transferring goods between modes. Combining intermodalism with containerization minimized this inefficiency (Mahoney 1985).

1.1.2 Containerization

Containerization is the transportation of cargo using standardized containers designed for easy interchange between modes, eliminating the re-handling of its contents. Special lifting equipment safely and efficiently transfers containers from one mode of transport to another. Containerization also protects the contents from damage and theft.

Containers were used in the early days of railroad transportation to reduce rail costs for the less-than-carload-load (LCL) service between stations, but they were not used for intermodal movement (Mahoney 1985). In 1847, the New York, New Haven, and Hartford Railroad and the Fall River Steamship Line experimented with using containers to help improve cargo transfer

between trains and steamships (Middendorf 1998). In 1921, the use of container-on-flatcar (COFC) services was initiated on the New York Central Railroad, which began hauling loaded steel containers between Chicago and Cleveland (New York Times 1921). The New York Central observed that transferring a container between modes required one fifth of the time needed to transfer cargo in the traditional piecewise manner. This substantial time savings increased asset utilization and presumably reduced operating cost (New York Times 1922).

The first experiment with modern containerization began in 1956, when the Pan-Atlantic Steamship Company (now part of Maersk) transported 58 truck-trailer vans on a steamship (Transportation Research Board 1992). The owner of Pan-Atlantic, Malcom McLean, envisioned that containerization would reduce the distribution costs associated with storing, packing, and shipping goods. After successful demonstration in the United States, intermodal containers began to be transported between East Asia and Europe. Following the container revolution in the shipping industry, railroads began developing ways to use containers. In 1972, the Sante Fe Railway ran the first containerized unit train service from Los Angeles to New Orleans (Solomon 2007). These unit trains were efficient because all containers were bound for the same destination and the train did not require sorting at intermediate railroad classification yards. A key element of successful intermodal service is sufficient traffic volume between origin and destination to justify unit train service.

1.2. RECENT HISTORY AND CURRENT OUTLOOK FOR RAIL INTERMODAL TRANSPORTATION

1.2.1 Intermodal Traffic Growth

The success of containerization has helped to make intermodal freight the second largest revenue source for North American railroads. In 2007, intermodal freight succeeded coal as the

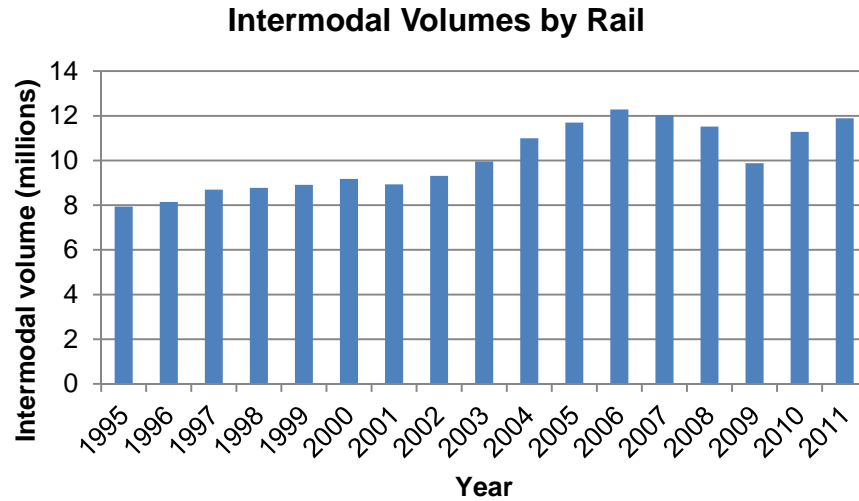


Figure 1.2 Annual intermodal traffic volumes by rail from 1995 to 2011 (AAR 2013)

number one revenue source, although it later dropped back to second place due to the economic recession. As the United States' economy continues to recover, intermodal traffic has steadily increased (Bowen 2012). Figure 1.2 shows the rail intermodal traffic volumes from 1995 to 2011. To accommodate future growth, railroads are expanding their intermodal service by upgrading existing terminals and building new terminals. They are also exploring the opportunity of providing intermodal service for shorter distances (200 to 300 miles) on the east coast, such as from Savannah to Atlanta, GA and from the Port of New York/New Jersey to Buffalo, NY and Pittsburgh, PA (Casgar et al. 2003).

1.2.2 Present Outlook

Although intermodal freight generates substantial revenue for North American freight railways (AAR 2013), its operating costs also tend to be higher due to the more demanding service requirements. Intermodal trains operate at higher speeds compared to bulk freight, in

order to compete with the trucking industry. They also tend to experience higher aerodynamic drag than bulk freight trains. The combination of these factors means that intermodal freight has higher fuel consumption per ton than other type of freight transported by rail.

1.3. OVERVIEW OF INTERMODAL AERODYNAMIC RESEARCH

Railroad fuel efficiency can be increased through use of new technologies and operating practices (ICF International 2009). Over the past few decades, railroads and researchers have investigated various methods of improving the energy efficiency of railroad transportation. Examples include the use of alternative fuels (Baker 1986), improving railcar truck performance (Allen et al. 1986), improving train handling (Arakelian 1986), using hybrid locomotives, and reducing train aerodynamic resistance. The majority of aerodynamics studies have consisted of wind tunnel testing and computer models that empirically calculate train aerodynamic drag (Hammitt 1976, Hammitt 1978, Hay 1982, Engdahl et al. 1986, Paul et al. 2009). These studies were used to develop computer software to estimate train aerodynamic resistance and train fuel consumption (Furlong 1987, Drish 1992, Airflow Science Corp. 2006). Railroads and researchers then applied the software to determine the energy savings gained from various container/trailer loading configurations on well cars, flat cars, and spine cars (Lai and Barkan 2005). The information from this research has helped intermodal terminals improve train energy efficiency by minimizing the gaps between loads in the front of train where the aerodynamic drag is highest (Daun 2010, White 2010).

Despite these improvements, previous research provided only limited discussion of the potential costs and consequences of improved loading. Improved train loading may require additional processing time at the terminal, which could interfere with the efficiency of other

terminal operations and override the energy savings gained from improved loading. This thesis seeks to better understand the processes at the intermodal terminal and how they could be affected by improving intermodal train loading. Additionally, this thesis will discuss loading metrics and machine vision technology, and how they can be applied to analyze current loading performance.

1.4. THESIS ORGANIZATION

After reviewing terminal operations and terminal performance metrics, I will review intermodal train loading metrics and discuss the potential challenges to maximizing the loading efficiency. Then, I will describe how machine vision can be used to assess the loading performance of intermodal trains. Finally, I will discuss how railroads can analyze terminal performance and the effects of improved loading using terminal computer data.

This thesis is divided into six chapters, including an introduction, conclusion, and four sections within the body where I address the following questions:

- What are the components of intermodal terminal geometry and operations and how is terminal performance measured? (Chapter 2)
- How do railroads measure intermodal train loading performance and how is loading performance affected by terminal operations? (Chapter 3)
- How can machine vision be used to assess train loading performance and aerodynamic efficiency? (Chapter 4)
- How can data collected from terminals be used to analyze terminal performance and determine the effect of improved loading? (Chapter 5)

Chapter 2:

Understanding the effects of improved loading practices on terminal performance requires an understanding of intermodal terminal operations and performance metrics. Intermodal terminal operations are divided into three sections: gate, yard, and lifting equipment. Each of these sections of operation involves its own personnel, equipment, and location in the terminal. Typical terminal performance metrics measure financial, safety, customer service, equipment, storage, and drayage performance. Although they measure specific contributions to terminal performance, these operations and metrics are interdependent.

Chapter 3:

Presented at the 2011 Joint Rail Conference (JRC) in Pueblo, CO and published in the conference proceedings (Rickett et al. 2011a)

Improving loading efficiency requires an understanding of current loading practices and metrics. Current North American railroad loading metrics consider equipment utilization, number of units, and/or total train length. However, these loading metrics do not account for the size of the well or platform and the size of the load placed in it. One proposed metric, slot efficiency, calculates the difference between the ideal container/trailer size for the slot and the actual size of the load placed in it. The slot efficiency metric can be compared to the current loading metrics using the Association of American Railroads (AAR) Aerodynamic Subroutine. The comparison shows that adopting the slot efficiency metric would enable railroads to better understand how their intermodal loading practices affect train energy efficiency. However, using the slot efficiency metric to improve loading practices can create challenges that are discussed in this chapter.

Chapter 4:

Presented at the 2011 Transportation Research Board (TRB) Annual Conference in Washington, D.C. and published in the conference proceedings (Rickett et al. 2011b)

There are opportunities to reduce intermodal train aerodynamic drag through improved equipment design and loading practices. The University of Illinois at Urbana-Champaign (UIUC) has developed a machine vision system to evaluate intermodal train energy efficiency based on the container/trailer loading arrangement, the gap lengths between loads, and the type of rolling stock used. A prototype machine vision system was installed at BNSF Railway's Logistics Park Chicago facility to demonstrate the feasibility of the system. This installation consists of a camera, computer, and machine vision algorithms. The system's outputs are the loading configurations and measurements, the gap length histograms, and the aerodynamic scores based on loading configurations and gap lengths. More recently, BNSF and UIUC installed an intermodal efficiency measurement system at a location on the BNSF Transcon, their principal intermodal route between Chicago and Los Angeles.

Chapter 5:

To understand the effects of improved loading practices, a time-motion study was conducted using terminal computer data from four intermodal terminals. Outbound and inbound data were collected for one month. Outbound data included the time the container or trailer arrived at the terminal gate, the time it was loaded onto the train, and the time when it was transferred from the terminal mainframe to the network mainframe. The inbound data included the time the container/trailer arrived on the train, the time it was unloaded from the train, and the

time it departed by truck through the terminal gate. The time-motion study seeks to understand the gate, lifting, and train processes of an intermodal terminal and to quantify the impact of improved loading practices. The results of the study can also help identify improvements needed in lean production, terminal capacity, and terminal performance.

CHAPTER 2: REVIEW OF OPERATIONAL AND PERFORMANCE METRICS FOR RAILWAY INTERMODAL TERMINALS

2.1. INTRODUCTION

In order to evaluate the performance of individual intermodal terminals and the intermodal network as a whole, it is necessary to first understand the components of intermodal terminals and how they interact with each other and the entire intermodal supply chain. Each of the 237 intermodal terminals in the US is unique in terms of its size, layout, lifting equipment, personnel, management strategies, storage capability, gate service capacity, and other variables. (IANA 2011). Intermodal terminal components and their interactions facilitate their primary purpose, the successful exchange of trailers/containers between carriers and customers.

This chapter provides an overview of intermodal terminal components and operations, including rail, drayage, and lifting operations. Additionally, this chapter discusses the metrics used to evaluate the performance of intermodal terminal operations, including financial, safety, customer service, lifting, and drayage performance metrics.

2.2. TERMINAL LAYOUT

Intermodal terminals can be located on either “brownfield” or “greenfield” sites. Intermodal terminals constructed on brownfield sites typically occupy locations of former flat-switched rail yards and often inhibit efficient intermodal terminal operations because of their square-shaped property layout and tracks that are too short to build a single intermodal train. Intermodal terminals perform better with a rectangular-shaped configuration and tracks long enough to build complete train consists (Lanigan et al. 2007). Another constraint is that many intermodal terminals that were upgraded from traditional rail yards have limited adjacent land available for expansion. Additionally, high land prices limit terminal expansion in cities leading

to construction of new terminals outside cities, at greenfield locations, where land is available and less expensive (Lanigan et al. 2007). However, constructing new intermodal terminals outside cities may be less convenient in terms of customer access. Ideally, a terminal is centrally located allowing ease of access to the largest customers in a region, thus reducing drayage costs and maximizing rail's share of the total trip distance. If a terminal is not within a convenient distance for the customer, they will use other modes to transport their freight.

2.2.1 Terminal Gate

The terminal gate is a means by which loads enter and exit the highway network or intermodal terminal (Figure 2.1); the other means is the track that connects to the rail network. The terminal gate has several functions. It serves as a control value by limiting congestion within the terminal thereby controlling access. Too many trucks inside a terminal can constrain its output. The gate also helps ensure the security of the cargo stored in the terminal. Typically, the gate is located close to the terminal office where operations personnel are available to assist drivers as they arrive and depart the terminal. To reduce processing time, terminal gates may have electronic kiosks where drivers input the necessary information to check containers or trailers in or out. Incoming loads are also inspected at the gate to identify cargo or equipment damage and assess when such damage may have occurred. Some terminals also inspect the condition of chassis owned by the rail carrier or a motor pool.



Figure 2.1 A terminal gate where load entry and inspections occurs

2.2.2 Storage Area

Beyond the terminal gate is the storage area where containers and trailers wait to be lifted onto a railcar for transport, or onto a drayage truck for delivery to a customer. Containers are either stored on chassis (Figure 2.2a) or stacked atop others directly on the ground (Figure 2.2b). Trailers cannot be stacked, so they are stored along with the containers on chassis. Storing containers on chassis can reduce truck turnaround time because these containers do not require additional (secondary) lifts. This storage method allows greater turnaround times for trucks but requires more space than stacked storage. Stacked storage requires more secondary lifts but can be very efficient when combined with gantry cranes or straddle carriers and a storage area alongside the strip track to minimize movements.



(a)



(b)

Figure 2.2 (a) Container stored on chassis (Buckeye Trailer 2013) and (b) stacked directly on the ground (FeaturePics 2013)

Stacked containers are organized by blocks, bays, rows, and tiers (Figure 2.3) (Kim 1997). A block of containers is divided into bays, where 20-foot containers occupy one bay and 40-foot containers occupy two bays. Typically, 20- and 40-foot containers are not mixed within a bay. A container's storage location is often identified by the row letter and tier number. For example, B3 indicates that the container is in row B and tier 3. Blocks within a terminal are typically segregated by origin, destination, train, or contents (e.g. hazardous materials) (Günther et al. 2000).

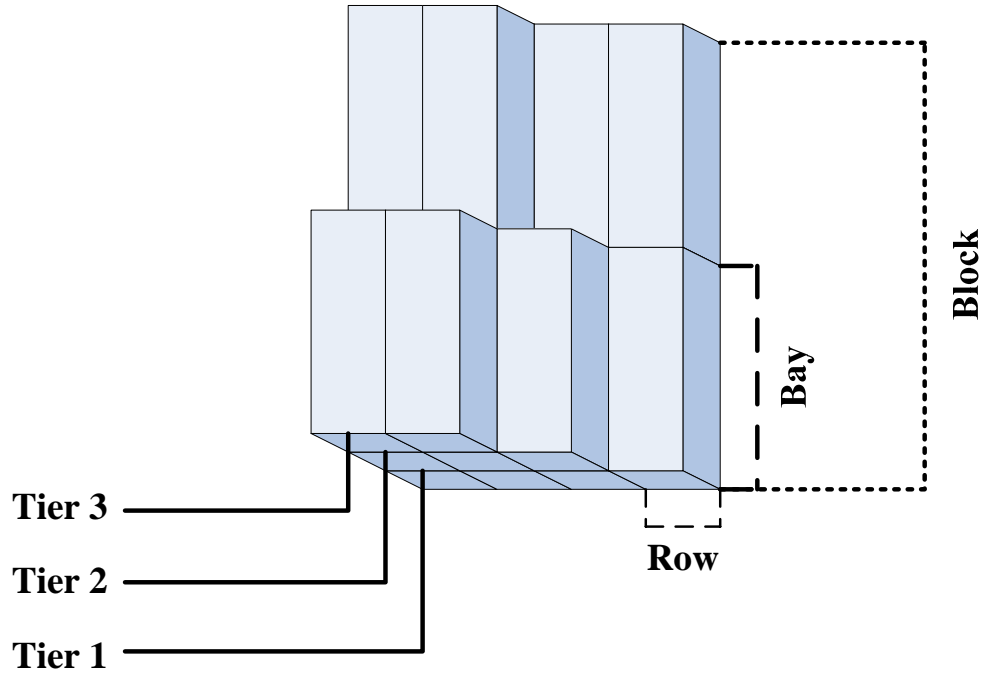


Figure 2.3 Stacked storage block diagram made up of bays, rows, and tiers

2.2.3 Track Types

Trains arrive at and depart from intermodal terminals via a nearby mainline track. Arriving trains enter the ladder track that diverges from the arrival and departure track and is connected to one or more strip or working tracks (New York State Department of Transportation 2004). The strip track is where railcars are switched and unloaded and loaded. Strip tracks have pavement extending the length of the track on both sides to allow trucks and lifting equipment to operate alongside railcars for loading and unloading. Strip tracks are sometimes single-sided only supporting lifting on one side due to space constraints, such as being on the edge of the terminal property, or adjacent to other tracks. Intermodal trains often arrive and depart directly from strip tracks rather than on separate receiving and departure tracks (White 2003). Terminals also have a bad-order track or area where railcars with mechanical defects are separated from

other cars and placed to await repair.

2.3. RAIL OPERATIONS

2.3.1 Switching

Switching is a railroad operation in which groups of connected railcars, typically from an arriving train, are separated and repositioned onto separate tracks (Daganzo 1983). However, intermodal trains generally require little switching because railcars frequently remain together for multiple trips. Instead, loads traveling to and from different origins and destinations are loaded on and off a train. If switching is necessary, it would occur on an intermodal terminal's strip track or a separate set of classification tracks.

When flat switching is needed, the railcars are coupled to a locomotive that typically pushes them onto the desired track. A yard brakeman rides on the railcar at the opposite end from this locomotive to watch for objects fouling the track and ensures switches are lined properly. When the railcars are properly spotted (i.e. placed), the brakemen uncouples them and the locomotive backs away leaving them in the desired position and track.

2.3.2 Railcar Inspections

The United States Department of Transportation (US DOT) Federal Railroad Administration (FRA) regulations require the inspection of mechanical and structural components of every car in a train before departure from a yard or terminal (US DOT 2010). However, no inspection is necessary when a train arrives at a terminal. Trains are required to have intermediate or Class IA inspections every 1,000 miles, or in some instances every 1,500 or 3,500 miles under specific conditions.

While all railroads must comply with FRA regulations, there are some procedural differences in their methods of compliance (Schlake 2010). Inspections must be carried out by qualified railroad personnel who are proficient in interpreting and applying the FRA regulations. Upon arriving at a terminal, a train is brought onto the receiving track, and the train crew uncouples the locomotive(s) after setting the hand brakes on a portion of the railcars (Schlake 2010). A crew then inspects the train under blue flag protection, which ensures that railcars will not be moved during the inspection (Schlake 2010). Typically, there are two carmen assigned to inspect one train, with one carmen inspecting each side. They look for mechanical defects that would compromise the train's safe operation. Minor defects can be repaired by the carmen using simple tools. Major defects, however, require more sophisticated equipment. When these are found, a bad-order form is completed and the car is moved to a location where suitable equipment and parts are available to complete the repair (Schlake 2010).

After the aforementioned elements of the mechanical inspection are completed, carmen conduct a test of the braking system to identify any leaks or reduction of the required airflow (Schlake 2010). For the initial or Class I inspection, all railcars must have operable brakes before leaving the terminal. For intermediate inspections, at least 85% of the railcar's brakes must be operable. If the air brakes cannot be repaired, carmen complete a bad-order form for the railcar. When the air test is completed, the brakes are released, and the air brake reservoirs are recharged. Carmen verify that the brake shoes are properly disengaged on each railcar. This can be evaluated by walking the train, or in a roll-by inspection (after the blue flag protection is removed) as the train departs the inspection location. When the standing mechanical inspection is complete, the carmen release the inspection track from blue flag protection and inform the train crew and the yardmaster that the train is ready for departure.

2.3.3 Intermodal Railcars

There are four basic railcar types used in intermodal transportation: two types of flatcars, spine cars, and well cars (Figure 2.4). The AAR Car Type Code for these four types are, respectively, F, P, Q, and S – each with their own loading capabilities. Intermodal railcars range from standard, all-purpose flat cars, to several types of specialized railcars designed for specific types of intermodal loads. Flatcars (F-type) have either a single, or two 85- or 89-foot load beds connected by a drawbar. Flatcars are flexible in terms of their lading; they can be used to transport containers, trailers, as well as other bulk freight. P-type railcars are conventional intermodal railcars that resemble flatcars but are specifically designed to haul intermodal containers and trailers. Spine cars (Q-type) are lighter versions of flatcars that can also carry both containers and trailers. Spine cars may have just one unit, or more commonly, three or five units connected by an articulated connection with intermediate units sharing a truck. The length of spine car loading platforms ranges from 48 to 57 feet. Well cars (S-type) are designed to carry double-stacked containers. To facilitate double-stack container operations, container-to-container connections are necessary (IBC connections or bulkhead), and terminals must monitor the lading weights to ensure that railcars are not overloaded. Due to their large surface area double-stacked containers are susceptible to overturning from heavy wind gusts (Pasta et al. 2010, Paul et al. 2009), and low tunnel or bridge clearances can restrict their use. As with spine cars, these may be single unit cars or three or five unit articulated cars.



(a)



(b)



(c)



(d)

Figure 2.4 (a) Flat car (F-type) (Dan D. 2006) (b) Conventional intermodal car (P-type) (Reinhart 2007) (c) 5-unit articulated spine car (Q-type) (TTX 2012) (d) 5-unit articulated well car (S-type) (The Kentucky Trainman nd)

2.4. DRAYAGE OPERATIONS

The underlying economic and logistical elements of intermodal transport are that a truck can pick up and deliver to almost any location in the highway network, but will generally be

more costly for long distance transport. Although the rail network is comparatively sparse, it can provide less costly long-distance transport. Drayage operations perform the collection and distribution of containers and trailers and connect the shippers and consignees, located on the highway network, with intermodal terminals on the railroad network.

2.4.1. Drayage Movements

Ileri et al. (2006) described the basic elements of the drayage process. For a load to be delivered by truck, a drayage order is created that specifies the pickup and delivery location, as well as the intermediate stops along the way. Drivers may need an extra stop to reposition an empty trailer/container to fulfill the next stop in their drayage order. A flexible order is another type of pickup and delivery request that has either a specified origin or destination, but not both. Draymen, who execute these orders, pick up and drop off loads at the intermodal terminal and may help the customer load and unload their shipments. A “drop-and-hook” stop occurs when a driver drops off their load and hooks up to another one at the customer’s location. A “live” stop occurs when a drayage truck must wait while its contents are unloaded and loaded (or vice versa).

2.4.2 Drayage Operations at a Terminal

Inbound movements occur when the drayage truck travels from the intermodal terminal to the customer. A common inbound movement is for the draymen to pick up a load from the terminal and then perform a drop-and-hook stop, picking up another load at the customer’s location. Another possible inbound movement is to pick up a load from the terminal and then perform a live stop at a customer’s facility.

Outbound movements occur when the drayage truck travels from the customer to the intermodal terminal. At the customer location, the drayage truck can either pick up a loaded container or trailer or drop off an empty container or trailer and pick up a loaded container or trailer. The truck then drops off the load at the terminal, where it is transported by hostler trucks and loaded by lifting equipment or is instructed by the terminal to bring the load to the track for immediate loading.

2.5 LIFTING EQUIPMENT

2.5.1 Hostler Trucks

Hostler trucks are vehicles used to transport loads within the terminal (Figure 2.5). They are easily operated and achieve higher speeds compared to vertical lifting equipment such as straddle carriers and reach stackers. If hostler trucks are unavailable, loads can be transported by some of the vertical loading equipment, but they operate at a slower speed. Hostler trucks are less expensive compared to other equipment types because of their low initial capital and maintenance costs; however, the equipment cost is higher because chassis are required for hostler trucks to handle containers.



Figure 2.5 Hostler truck operating in an intermodal terminal (Calstart 2008)

2.5.2 Straddle Carrier

Straddle carriers drive alongside containers and can lift a container from a stack of up to four containers high (Figure 2.6). Straddle carriers enable more efficient use of terminal land because they can drive astride container stacks, and lift up to 100,000 pounds. They can achieve quick turnaround times due to their ability to hoist loads while moving (Lowe 2005, Alderton 2008). Straddle carriers are maneuverable and have good visibility because of the location of the operator's high cockpit. However, they require a high level of skill to operate (Alderton 2008). Additionally, the infrastructure cost of straddle carriers is higher than the cost of hostler trucks and chassis because they require stronger pavement structure than other loading equipment. They have a medium equipment cost and a high unit maintenance cost (Alderton 2008).



Figure 2.6 Straddle carrier picking up a container (Fantuzzi 2013)

2.5.3 Gantry Crane

Gantry cranes (Figure 2.7) have a lifting capacity of 50,000 to 100,000 pounds and can span multiple rows of stacked containers, loading/unloading tracks, and/or truck-loading lanes (Lowe 2005). Of all the types of terminal lifting equipment, gantry cranes have the highest land utilization rating because they can traverse several rows of containers and/or tracks and can lift and place containers on tall stacks. Gantry cranes require a medium-high level of skill to operate. Gantry cranes have a high equipment cost, and they require a significant load-bearing pavement foundation, making the overall facility cost higher as well. Compared to straddle carriers and front-end loaders, gantry cranes have low unit maintenance costs but high capital costs.



Figure 2.7 Wide-span rail-mounted gantry crane in operation at BNSF's Seattle International Gateway (Oil Electric 2011)

2.5.4 Reach stacker

A reach stacker (Figure 2.8) is a maneuverable lifting vehicle with an overhead hydraulic lifting arm used to lift containers or trailers weighing up to 90,000 pounds (Lowe 2005, TEREX 2011). Reach stackers are capable of lifting containers from the top of a stack of five containers, resulting in high land utilization. They require a medium amount of skill to operate. Like gantry cranes and straddle carriers, reach stackers require a strong pavement foundation for operation and have moderate maintenance costs.



Figure 2.8 Reach stacker with the capability of picking up a container from a stack of five containers (Hyster 2013)

2.5.5 Front-end Loader System

Front-end loaders operate similarly to reachstackers, but they cannot lift containers from stacked storage (Figure 2.9). Typical loading capabilities for front-end loaders are 44,000 to 90,000 pounds, and they require a medium level of skill to operate (Lowe 2005). Because of poor weight distribution and torsional movements, rigid pavement surfaces are required at terminals that use front-end loaders. They do not enable as efficient land utilization because they cannot reach containers in stacked storage, and they have moderate terminal development, equipment, and maintenance costs (Alterton 2008).



Figure 2.9 Front-end loader lifting a domestic container

The variability of lifting equipment (Table 2.1), drayage traffic, load sizes and types, and railcar equipment and operations all affect intermodal transportation efficiency. The unique characteristics of each terminal makes quantifying terminal performance challenging, especially when determining how one attribute (e.g. train arrivals) can affect the performance of other attributes (e.g. lifting activities and container departures from the terminal gate). The next section describes methods to measure intermodal terminal performance.

Table 2.1 Lifting Equipment and Hostler Truck Summary

Type	Operating Skill	Total Cost	Land Utilization	Highest Reach on a Container Stack	Lifting Capability (pounds)
Hostler Truck	Low	Low	Low	1	N/A
Straddle Carrier	High	Medium	High	4	100,000
Gantry Crane	Medium	High	Highest	5	50,000-100,000
Reach Stacker	Medium	Medium	High	5	90,000
Front-end Loader	Medium	Medium	Medium	1	44,000-90,000

2.6. EVALUATING INTERMODAL TERMINAL PERFORMANCE

The literature contains extensive research on intermodal terminal efficiency simulation and optimization (Bontekoning et al. 2004, Steenken et al. 2004), but only few sources provide a thorough discussion on how to evaluate intermodal terminal performance. Overall intermodal terminal performance consists of the summation of several sub-components such as finance, safety, customer service, lift equipment utilization, load storage density, and drayage efficiency. Each of these components will be discussed in the following sections.

2.6.1 Common Terminal Performance Metrics

Four common methods for measuring the performance of intermodal terminals are turnaround time, plant utilization, throughput, and productivity (Fierra and Sigut 1993, Ockwell 2001). Turnaround time is the time that elapses from when a truck enters a terminal to when it departs the terminal (Ockwell 2001). Plant utilization is used to calculate how well the terminal uses its lifting equipment, service tracks, and gates. Throughput measures the terminal output per unit of time (Tioga Group 2010). Productivity measures the terminal output - either lifts or intermodal loads - per unit of input (e.g. man-hours or trains, etc.) (The Tiago Group 2010).

2.6.2 Financial Performance

Financial performance evaluates how a terminal uses its financial resources to achieve a certain level of productivity and profit. A terminal's resources consist of facilities, labor, and equipment. Terminal facilities consist of the gate, storage area, service tracks, office space, and repair shops. Labor at a terminal includes lifting operations, mechanical repairs, security, gate operations, transportation, and management. Equipment at a terminal consists of chassis,

railcars, lifting equipment, hostler trucks, information technology, and yard engines. Terminal equipment costs can be estimated using Equation 2.1; terminal facility costs can be quantified using a similar equation.

$$\text{Equipment Costs} = \frac{\sum_{j,n} O_{j,n} + I_{j,n} + M_{j,n} + A_{j,n} + C_{j,n}}{\sum_n L_n} \quad (2.1)$$

Where:

$O_{j,n}$ = operating costs for equipment j for time period n

$I_{j,n}$ = insurance costs for equipment j for time period n

$M_{j,n}$ = maintenance costs for equipment j for time period n

$A_{j,n}$ = aging costs for equipment j for time period n

$C_{j,n}$ = lift cycle costs for equipment j for time period n

L_n = number of lifts for time period n

As rail carriers develop new or upgrade existing terminals, financial performance should also consider costs and benefits to the nearby community. The financial benefits to the community include job creation and regional economic development.

Job creation can be quantified as the total number of job years from both terminal construction and operation divided by the total investment. Regional economic development can be approximated as the value of the intermodal freight through the terminal divided by the investment in the terminal (Equation 2.2).

$$\text{Economic Development} = \frac{V_f - V_i}{I} \quad (2.2)$$

Where:

V_f = total value of freight after investment

V_i = total value of freight before investment

I = investment in terminal

Terminal financial performance can be improved by either increasing the terminal's output while holding operating costs constant or improving terminal efficiency. Efficiency improvements include increasing equipment utilization, decreasing number of secondary lifts and safety incidents.

2.6.3 Safety Performance

The safety of the workers and the cargo is considered in terminal safety performance. Fewer safety incidents help minimize terminal stoppage time and allow for more productive operating hours. For employee and terminal-wide safety, terminals typically count the number of days since the last safety incident where a worker or driver is injured. The goal is to accumulate as many days as possible without any accidents or incidents. Another method is quantifying the number of safety incidents divided by the number of lifts during in a time interval (Equation 2.3).

$$\text{Safety Incidents per Lift} = \frac{S_n}{L_n} \quad (2.3)$$

Where:

S_n = number of safety incidents in time period n

L_n = number of lifts in time period n

Another option for measuring safety is quantifying the delay in terminal productivity when a safety incident occurs. Also, the severity of an incident can be calculated by summing the costs associated with productivity delay, property damage, and injury and then dividing this total cost by the number of lifts over the same time period.

The safety of the cargo can be quantified by either summing the damages of mishandled and lost loads or the number of damaged and lost loads divided by the number of lifts over a given time period (Equations 2.4 and 2.5).

$$\text{Load Damage per Lift} = \frac{\sum_k D_{k,n} + \sum_m D_{m,n}}{L_n} \quad (2.4)$$

Where:

$D_{k,n}$ = Cost in dollars for damaged load k in time period n

$D_{l,n}$ = Cost in dollars for lost load m in time period n

L = number of lifts in time period n

$$\text{Load Mishandles per Lift} = \frac{K_n + M_n}{L_n} \quad (2.5)$$

Where:

K_n = number of damaged loads in time period n

M_n = number of lost loads in time period n

L_n = number of lifts in time period n

Terminals should also consider the safety impacts to nearby communities by quantifying the emissions generated from the terminal, the increased number of truck accidents nearby, and the number of trailers and containers with hazardous materials and their resulting risk.

Emissions can be reduced by limiting drayage truck idling at the gate, purchasing low-emission yard locomotives, and using electric-powered gantry cranes. Incentivizing truck drivers to deliver and pick up loads before or after regular business hours or on weekends may mitigate traffic accidents as well as congestion near the terminal.

2.6.4 Customer Service Performance

Customer service performance measures the customer's expectations and perception of service at a terminal. A customer makes shipping decisions based on transit times, reliability, damage-free delivery, and cost (Ferreira and Sigut 1993). Reliability can be quantified as a percent of on-time train departures and arrivals over the total train departures and arrivals. Jin et al. (2004) quantify reliability and mobility using travel time, route distance, and tons hauled (Equations 2.6 and 2.7).

$$Mobility = \sum_{i,j} \frac{T_{i,j}}{l_{i,j}} \forall m \quad (2.6)$$

$$Reliability = \frac{\sqrt{\sum_{i,j} \frac{p_{i,j} \times l_{i,j} \left(\frac{T_{i,j}}{l_{i,j}} - Mobility \right)^2}{p_{i,j} \times l_{i,j} - 1}}}{Mobility} \forall m \quad (2.7)$$

Where:

$T_{i,j}$ = travel time from origin i to destination j

$l_{i,j}$ = route distance from origin i to destination j

$p_{i,j}$ = tons hauled from origin i to destination j

m = mode of transportation

A higher reliability value implies lower variability in mobility so customers can better predict load arrival times and experience less delay. Reliability is affected by both delays at terminals and along the intermodal network outside of the terminal. Delays along intermodal corridors can be caused by congestion, maintenance and construction activity, or service outages. Delay at the terminal may be caused by congestion at the loading area and gate, safety incidents, or other late trains that need to be loaded or unloaded first.

2.6.5 Lifting Equipment Performance

Lifting equipment performance at an intermodal terminal can be measured using the lifting ratio, shown in Equation 2.6.

$$\text{Lifting Ratio} = \frac{L}{T} \quad (2.6)$$

Where:

L = total number of primary and secondary lifts per unit of time

T = total number of loads handled per unit of time

The lifting ratio considers the average number of times a load is handled. The lifting ratio can be improved by reducing secondary lifts by using less stacked storage. However, less dense storage limits the available space for other containers and trailers and terminal output. Lifting equipment performance can also be calculated using the terminal's machine utilization and its machine availability (Ferreira and Sigut 1993).

$$\text{Machine Availability} = \frac{T_R - T_D}{T_R} \quad (2.7)$$

Where:

T_R = machine's total scheduled operating hours

T_D = machine's total down time for repairs and maintenance

$$\text{Machine Utilization} = \frac{T_A}{T_R - T_D} \quad (2.8)$$

Where:

T_A = total time that the machine is used in production activities

Machine availability and utilization can be improved by increasing the vehicle's working hours or reducing repair and maintenance times. However, increasing the machine's available working hours or reducing repair times may cause more frequent and/or severe machine down times to conduct larger repairs. Lengthening working hours may also result in increased operating expenses to pay for additional repairs and/or equipment replacement.

2.6.6 Load Storage Density Performance

Lifting equipment performance at an intermodal terminal can be measured by load dwell time and by storage density. Dwell time is the length of time a load remains in an intermodal terminal. Any portion of dwell time where the load sits idle is unproductive and is often avoidable. Therefore, a terminal's throughput can increase by reducing load dwell time (Huynh 2008). Institutional and/or operational changes can help minimize unproductive dwell time. Storage density (2.9) measures how densely containers are stored in a terminal is defined by Huynh (2008) as:

$$\text{Storage Density} = \frac{V}{a} \quad (2.9)$$

Where:

V = number of loads at the terminal

a = terminal area (acres)

As with reducing dwell time, increasing storage density can help improve throughput (Huynh 2008). Stacking containers increases storage density, but removing stacked containers can require additional handling of the other containers in the stack. Re-handling can, in turn,

increase dwell time, increase truck turnaround time, and monopolize the utilization of loading equipment. Therefore, adjustments to storage density and dwell time needs to be balanced to maximize throughput and avoid compromising the performance of other terminal elements.

2.6.7 Drayage Performance

Drayage performance at an intermodal terminal is measured by the number of non-revenue drayage movements to the total number of drayage movements. Operating time, truck movement, hostler traffic flow, and destination proximity are some elements that affect drayage performance. Reducing drayage operating time can reduce drayage costs. The time drayage trucks spend at terminals and customer locations can be reduced by providing more efficient document settlement, a sufficient number of loading docks at shipper and consignee locations, ample staff to load/unload, a sufficient handling capacity at the terminal, and good communication between parties (Konings 2008). Reducing non-revenue drayage movements can reduce costs but may reduce the level of service. Drayage operations can be coordinated by sharing information between carriers and customers to increase load density; however, such coordination may reduce the level of service provided.

2.7. CONCLUSION

This chapter described the rail, drayage, and lifting operations occurring at intermodal terminals, as well as types of railcars and lifting equipment. Financial, safety, customer service, storage, lifting equipment, and drayage performance and performance metrics were also discussed.

As the intermodal traffic volumes increase and terminal expansion may be financially or physically infeasible, an alternative is implementing operational efficiency improvements to

increase productivity as well as decrease costs. For example, the intermodal transportation industry is currently replacing trailers with containers to improve loading and storage efficiency and increase load capacity on trains. However, this will require larger chassis pools, limiting load storage capacity and requiring additional maintenance costs for chassis. In the same way that containers can both benefit and harm terminal operations, the next chapter will discuss intermodal train loading performance and how improved loading may affect terminal operations.

CHAPTER 3: INTERMODAL TRAIN LOADING METRICS

3.1 INTRODUCTION

The second largest source of revenue for North American railroads is the transport of intermodal freight, which continues to grow as the United States' economy recovers (Boyd 2011). In comparison to truck transport, railway intermodal transport is more efficient due to the low-friction steel wheel on steel rail interface, closely coupled railcars, rolling stock capable of transporting multiple trailers and/or containers on a single railcar, and the ability to form long trains operated by small number of personnel. To maximize the efficiency of their intermodal operation, railroads monitor and evaluate the use of loading positions or “slots” on intermodal railcars using several types of quantitative loading metrics.

In spite of its energy efficiency relative to trucks, rail intermodal freight has a higher fuel consumption rate than most railroad bulk freight (AAR 2009a, FRA 2009). This is due to its greater aerodynamic drag and the higher operating speeds required to effectively compete with trucks. In 2007, Class I railroads spent \$12.2 billion on fuel, representing 25.8% of their total operating expenses (AAR 2009a). Maximizing the use of railcar wells and platforms improves asset use and operating efficiency. It also minimizes the gap lengths between loads thereby reducing aerodynamic drag and improving fuel efficiency (Lai and Barkan 2005). Therefore, developing loading metrics that incentivize terminal personnel to minimize gap lengths is of interest to railroads. In this chapter, I review the loading metrics used by North American railroads, identify the strengths and weaknesses of each, compare them using loading scenarios, and quantify their respective aerodynamic resistance using computer software developed by the

Association of American Railroads (AAR). I will also identify potential challenges railroads face when improving the loading efficiency of intermodal trains.

3.2 OVERVIEW OF INTERMODAL TERMINAL OPERATIONS

In order to evaluate the performance of intermodal train loading, it is necessary to understand the key elements affecting the loading process. Container and trailer traffic flow, rolling-stock and lifting equipment constraints, switching operations, train schedules, and other elements of terminal operations can all affect this process.

Loads in the form of either containers or trailers arrive at a terminal either by truck or inbound train. When arriving by truck, loads enter the terminal gate where they are checked in and inspected to assess their condition and ensure that no damage occurred in transit. During check in, the load's size, initials, number, and destination terminal are entered into a data system. Using this information, a clerk or programmer assigns the load to a specific position or slot on a railcar and appropriate terminal personnel are notified that it is available for loading. Loading assignment is typically done manually using computer software that checks to ensure compatibility between the load and the slot, and that no loading violations occur. Following check-in and inspection, the truck driver is instructed to park the load in a designated zone to await transfer to a train at a later time, or to park beside a particular track for immediate loading onto an outbound train.

Meanwhile, the terminal yardmaster arranges the available rolling stock to make up blocks for outbound trains. The railcars used for trains typically come from recent inbound trains, or are already at the terminal in storage. When the clerk or programmer determines the specific location for a load, a work order is generated and sent to the loading crew who may be either a railroad employee or a contractor. In the latter case, contract employees are generally

compensated based on the number of primary lifts they complete. Primary lifts include loading or unloading a trailer or container on or off a railcar. All other lifts, such as stacking the loads in storage or staging the load beside the track, are classified as secondary lifts. If loads are not transferred directly to or from an outgoing or incoming train, then they are temporarily stored in a designated area. In this case, drivers known as “hostlers” transfer loads between the parking zone and the track as needed. Lifting operators use machinery such as side loaders, reach stackers, or gantry cranes to load the containers and/or trailers onto the train. The clerk then verifies the completed work order to ensure that the load was correctly placed in the specified railcar slot. If it was loaded in an incorrect location, the crew moves it to the correct location. This process continues until the cut-off time is reached, at which point additional loads are no longer placed on the train. The train is then released to railroad transportation personnel, the air brake train line and reservoirs are charged, and an initial terminal brake test is conducted prior to train departure.

Efficient terminal operation is critical for on-time train departure and arrivals. Improvements to terminal operations and efficiency must not compromise safety, network performance, or customer service performance. Consequently, these must be taken into consideration when proposing changes in loading practices that are intended to maximize train capacity and energy efficient operation.

3.3 REVIEW OF LOADING METRICS

Although each intermodal terminal is unique in terms of layout, design, lifting equipment, loading personnel, train characteristics and schedules, many terminals use the same loading metric(s). Intermodal train loading performance metrics allow trains to be compared

using consistent, objective standards, but various constraints related to the individual characteristics of a terminal, or its traffic, may affect the utility of different metrics.

3.3.1 Slot Utilization

The most common loading metric used by North American railroads is slot (or platform) utilization. Based on site visits and discussions with intermodal operations management, most Class I railroads evaluate train loading using this metric. “Slot utilization” is defined as the percentage of slots (positions in a railcar) filled with either trailers or containers. A slot refers to a platform or well location on a railcar where a load can be placed. Slot utilization promotes the use of all slots for all rolling stock in the train, including double-stacked containers in well cars. Slot utilization is defined as:

$$Slot\ Utilization = \frac{\sum_{i=1}^n a_i}{\sum_{i=1}^n u_i} \quad (3.1)$$

Where:

i = the i th railcar in the train

n = the total number of railcars in train

a_i = the number of slots loaded in railcar i

u_i = the total number of slots in railcar i

For example, a five-unit, articulated well car has a total of ten slots. If it has a single container in one well and the other four wells are double-stacked, its slot utilization is 90% (Figure 3.1a). If a

container is added on top of the load in the single-stacked middle well, the slot utilization would increase to 100% (Figure 3.1b).

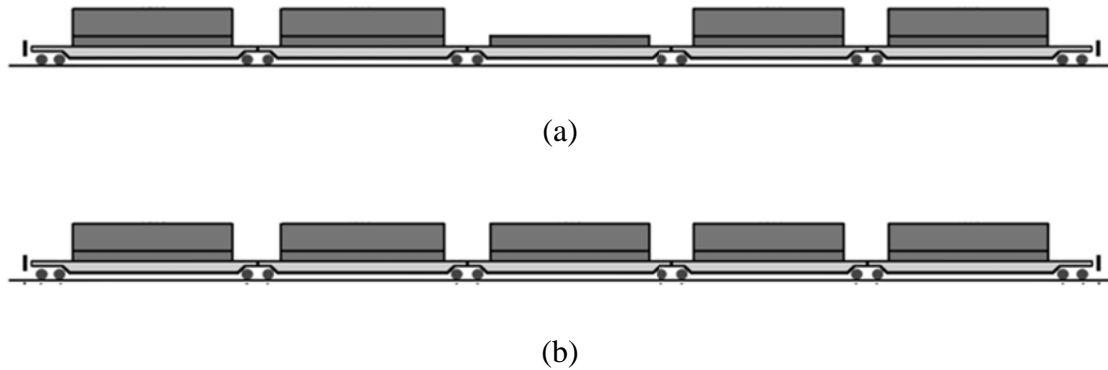


Figure 3.1 A five-unit well car with (a) 9 of the 10 slots filled and (b) 10 of 10 slots filled representing 90% and 100% slot utilization

To determine a railcar's ideal number of loads, the car's loading configuration must be known. Terminals keep track of this information by generating reports summarizing outbound train slot utilization. Slot utilization's simplicity and ease of calculation makes it a useful tool for measurement of intermodal train loading efficiency.

3.3.2 Train Feet Per Unit

One Class I railroad recently adopted a new loading metric called train feet (ft) per unit (TFPU) as an alternative to slot utilization. Note that the word "unit" in the definition of TFPU refers to a load on the train. In this chapter, a "unit" refers to intermodal railcars that may be divided up into one, three, or five units connected to one another by an articulated truck. Each unit has either a platform with one available slot or a well with two available slots. Instead of summing the number of loads per railcar as is the case with slot utilization, it sums the outside

length of all railcars in the train compared to the total length of all the loads on the train. TFPU is calculated as follows:

$$TFPU = \frac{\sum_{i=1}^n L_i}{\sum_{i=1}^n U_i} \quad (3.2)$$

Where:

i = the i th railcar in the train

n = the total number of railcars in the train

L_i = the outside length of railcar i

U_i = the number of loads in railcar i

TFPU can also be measured as a percentage score by taking the ideal TFPU and dividing it by the train's actual TFPU. Typical ideal TFPU values are approximately 60 ft/load for spine cars, 70 ft/load for single stack well cars used for domestic containers, 35 ft/load for double stack well cars for domestic containers, 53 ft/load for single stack well cars, and 26.5 ft/load for double stack well cars for international containers (White 2010). These values are determined by averaging the ideal TFPU values for similar types of rolling stock. Railcar lengths may vary among the same railcar types because of the number of units and/or manufacturer design. For example, the ideal TFPU for a five-unit TTAX spine car with a total length of 290 ft and five platforms is 58 ft/load, whereas the ideal TFPU for a three-unit TTAX spine car with a total length of 179 ft and three platforms is 59.6 ft/load. It would be more precise to calculate the

ideal TFPU for each railcar, but instead a higher average value is chosen to minimize the penalty for longer rolling stock. The ideal TFPU can be determined using the following equation:

$$Ideal\ TFPU = \frac{\sum_{i=1}^n L_i}{\sum_{i=1}^n P_i} \quad (3.3)$$

Where:

i = i th railcar in the train

n = total number of railcars in the train

L_i = outside length of railcar i

P_i = ideal number of loads for railcar i

TFPU utilization is determined by dividing the ideal TFPU by the actual TFPU. The ideal number of loads for a railcar and the railcar length can be obtained from the AAR (2009b) Loading Capabilities Guide or the Universal Machine Language Equipment Register (UMLER) database (Railinc Corporation 2011). Referring back to Figure 3.1a, if the railcar's outside length is assumed to be 260 ft (5 cars with 48-ft wells), then the actual TFPU for (a) is $260/9 = 28.89$ ft/load, giving a TFPU utilization of $26.00/28.89 = 90\%$. For the example in Figure 3.1b, the ideal and actual TFPU values are equal so the TFPU utilization is 100%. For this scenario, both slot utilization and TFPU utilization scores were the same; however, under many circumstances they will not be. Depending on the ideal TFPU value, a train's TFPU utilization can be greater than 100% if it has more loads than slots. This will be discussed in more detail in Section 3.6.

3.3.3 Slot Efficiency

A third metric that can be used to evaluate the loading of intermodal trains is slot efficiency (Lai and Barkan 2005). Slot efficiency considers not only the length of wells or platforms, but also the length of the loads. The inclusion of load lengths enables a more precise comparison between the actual and ideal load configuration, while also identifying empty slots in the train. As was the case with TFPU calculations, the ideal load lengths for a railcar can be found in the AAR (2009b) Loading Capabilities Guide or the UMLER database (Railinc Corporation 2011). Using this information, slot efficiency is calculated as follows:

$$\text{Slot Efficiency} = \frac{\sum_{j=1}^m l_j}{\sum_{j=1}^m t_j} \quad (3.4)$$

Where:

j = j th slot in the train

m = total number of slots in the train

l_j = actual load length(s) in slot j

t_j = ideal load length in slot j

For example, 40-ft containers double-stacked in a 53-ft slot well car would have a slot efficiency of 75%. Loading 53-ft containers instead of 40-ft containers onto the same car would increase

slot efficiency to 100% whereas slot utilization would be unchanged. The inclusion of slot length and load length make slot efficiency a good tool to evaluate how well loads and platform/well sizes are matched, and also provide an objective metric for quantifying the energy efficiency of intermodal trains.

3.4 INTERMODAL TRAIN AERODYNAMIC EFFECT ON ENERGY EFFICIENCY

North American intermodal rolling stock consists of flat cars, spine cars, and well cars (Figure 3.2). These cars have a variety of designs and loading capabilities that result in varying gap lengths between loads on adjacent railcars or platforms/wells. If gaps between loads exceed 6 ft, the loads are considered aerodynamically distinct and the resultant aerodynamic drag increases substantially due to the change in the boundary layer (Engdahl et al. 1986).

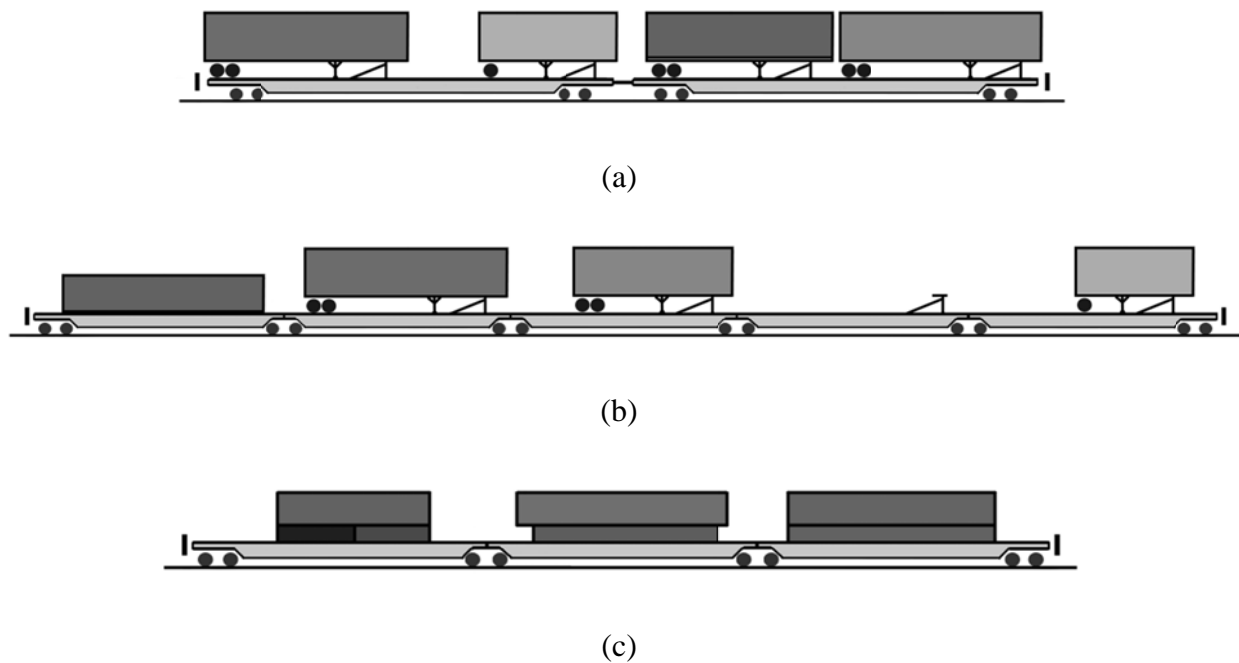


Figure 3.2 Typical North American intermodal rolling stock: (a) two-unit flat car with trailers (b) five-unit articulated spine car with a container and trailers,

(c) three-unit articulated well car with double stacked containers

3.4.1 Train Resistance and Fuel Consumption

Train resistance is the summation of frictional and other forces that a train must overcome in order to move (Hay 1982):

$$R = A + BV + CV^2 \quad (3.5)$$

Where:

R=total train resistance (lb)

A=bearing resistance (lb)

B=flange resistance (lb)

V=velocity (mph)

C=aerodynamic resistance (lb/mph/mph)

Bearing resistance varies with the weight of the railcar or train, flange resistance varies linearly with train speed, and aerodynamic resistance increases exponentially with velocity. To relate a train's aerodynamic resistance to fuel consumption, Paul et al. (2009) referenced an equation used to estimate fuel consumption based on a train's weight, speed, and aerodynamic drag:

$$F = K(0.0015W + 0.00256S_dV^2 + CW) \quad (3.6)$$

Where:

F= fuel consumption in gal/mi

K= fuel consumed per distance traveled per unit of tractive resistance = 0.2038

W = train's total weight (lb)

S_d = consist drag area (ft²)

V = train speed (mph)

C = hill factor = 0.0 for level routes and 0.0007 for hilly routes

Due to the exponential relationship between speed and aerodynamic resistance, reducing the aerodynamic coefficient is of particular importance for intermodal trains because of their high operating speed. Using the fuel consumption equation from Paul et al., a train of three locomotives with 30, three-unit well cars, with 53-ft wells traveling at 70 mph can reduce its fuel consumption by 0.1 gallons of fuel per mile, per percent reduction in the train's drag area. Over thousands of train miles, this can result in a significant fuel savings and operating cost reduction. Aerodynamic drag reduction can be accomplished in several ways including redesign of intermodal rolling stock, installing aerodynamic reduction attachments, container or trailer design improvements (Paul et al. 2009), and improved terminal loading practices (Lai and Barkan 2005). Redesigning railcars, containers or trailers would require substantial capital investment and involve various design considerations and possible constraints regarding compatibility with container and trailer types. Improved loading practices may provide an economical alternative to such design changes.

3.4.2 Optimizing Intermodal Train Loading

Lai and Barkan (2005) compared the benefits of slot efficiency and slot utilization. The potential savings from switching from 100% slot utilization to 100% slot efficiency can be as much as one gallon of fuel per mile, depending on the specific rolling stock and loads available.

Additionally, Lai et al. (2007a) developed an optimization model that minimized a train's gap lengths given a particular set of loads and rolling stock. Lai et al. (2008) expanded the earlier optimization model to account for the uncertainty of incoming load types, and simultaneous loading of multiple trains. In addition to this type of modeling, the BNSF Railway is developing a machine vision system that will be used as a diagnostic tool to evaluate current train loading practices and future loading improvements (Lai et al. 2007b, Rickett et al. 2011). This system is described in Chapter 4.

3.5 EVALUATION OF LOADING METRICS

A juxtaposition of loading metrics and train aerodynamics shows how loading affects energy efficiency. A more detailed critique reveals the limits of each loading metric to holistically describe changes that would be beneficial from an aerodynamic drag reduction standpoint.

3.5.1 Slot Utilization

Slot utilization is the most basic and the least specific of the three metrics described because it only considers empty slots in the train. It does not account for the capability of the railcars nor minimization of the gap length between loads. In comparison to TFPU, slot utilization does not reward terminal managers for loading more than one load in a slot (such as two 20-ft containers in one 40-ft or larger well car). However, for railroads that are limited in double stack capability due to clearance restrictions, it may not be advantageous to adopt slot utilization because the scores will not reflect operational constraints of some corridors. Also, if a railroad wants to identify which destinations' blocks are underutilized, the metric does not

discriminate between different blocks on the train unless all of its loads are bound for a single destination (Quoram Corporation 2007).

3.5.2 Train Feet Per Unit

TFPU provides a more detailed analysis of intermodal train loading because it considers the equipment used to make up the train's consist. This metric promotes the reduction in train length while still maximizing the number of loads. TFPU can also help reduce operating costs and increase revenue generation for each train by reducing its length (Daun 2010). However, like slot utilization, it cannot be used to determine how well loads were matched with the appropriate well or platform size. Also, the TFPU utilization score is the same as the slot utilization score except that it quantifies the total number of loads rather than whether or not each slot in the train was utilized. The TFPU metric is biased towards trains that have 20-ft containers and/or 28-ft trailers because they can achieve higher scores than trains that have larger load sizes. However, this could be useful for terminals that are limited in double stack capability by giving their trains higher scores for using smaller loads. The TFPU metric would not penalize this scenario when the top of a well car could not be used due to weight restrictions or certain load incompatibilities. The use of the ideal TFPU can be adopted to reflect the context of the operational limits of trains on particular routes such as clearance restrictions.

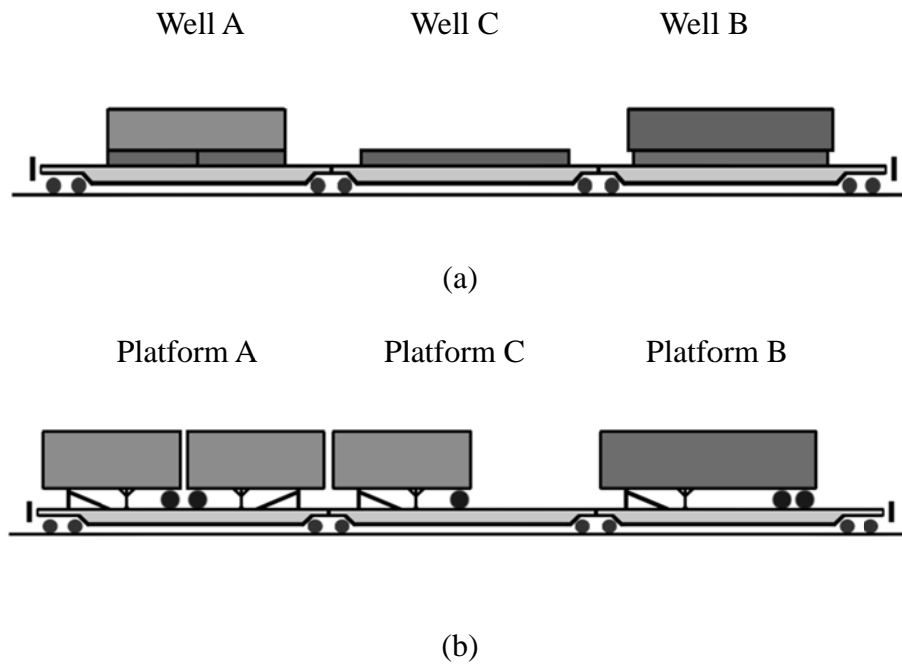
3.5.3 Slot Efficiency

In comparison with other two loading metrics, slot efficiency is the most specific because it considers both the length of the wells and/or platforms and its loads. However, the specificity of this metric makes it difficult to decipher whether a train has empty slots or if the loads do not

match their assigned slots. From an aerodynamic point of view, this metric does not account for the location of the minimized gaps. This could result in the loading being very good in the middle and back of the train, but poor in the front where aerodynamic penalties are highest. Nevertheless, the following scenarios and variations show that slot efficiency is generally the best estimate for improvements in energy efficiency from changes in loading.

3.6 ANALYSIS OF LOADING METRICS

To provide a further comparison of loading metrics, two scenarios are introduced. These scenarios help illustrate the strengths and limitations in the various loading metrics. Also, an analysis of the scenarios was conducted to see how incremental changes in train loading will affect the loading score and the train's aerodynamic performance. The aerodynamic coefficient for each train was determined using a software program developed by the AAR called the Aerodynamic Subroutine (Furlong 1988). The first scenario, A, is a train pulled by three EMD locomotives with the short hoods facing forward. There are 30, three-unit stack cars, with 53-ft wells based on a TTX railcar. The wells can hold two 20-ft containers or one 40, 45, 48, or 53-ft container in the bottom slot and a 40, 45, 48, or 53-ft container on top (AAR 2009b). Well A has two 20-ft containers in the bottom slot and a 40-ft container on top. Well C has a 53-ft container in the bottom slot and no load on top. Well B has a 48-ft container in the bottom slot and a 53-ft container above it (Figure 3.3a). The second scenario, B, is a train with the same locomotives as in Scenario A, and 30 three-unit articulated spine cars with 57-ft platforms. Platform A has two 28-ft trailers, Platform B has one 28-ft trailer, and Platform C has a 48-ft trailer (Figure 3.3b).



**Figure 3.3 (a) Loading Scenario A (well cars with 53-ft wells)
and (b) Scenario B (spine cars with 57-ft platforms)**

3.6.1 Analysis of Scenario A: Containers in Well Car

For Scenario A, five out of six possible slots are used, thus the slot utilization is 83%. For TFPU if we assume that the railcar's length is 203 ft (67.67 ft per unit), then the train's actual TFPU is:

$$Actual\ TFPU = \frac{30 \times 203ft}{30 \times (2 + 1 + 0 + 1 + 1 + 1)loads} \quad (3.7)$$

$$Actual\ TFPU = 33.83\ ft/load$$

If the ideal TFPU is 33.83 ft/load, which represents a well having two loads, then the TFPU utilization is 100%. If trains along the route are limited to single stack well cars due to clearance restrictions and the ideal TFPU was 67.67 ft/load, then the score would double. If the ideal TFPU was 22.56 ft/load assuming three loads per well, then the TFPU utilization would be 66.7%. In this scenario, the two 20-ft containers make the TFPU utilization score appear as if all slots are utilized when in fact one of the six slots is empty. This scenario illustrates how terminals could use 20-ft containers to achieve a perfect loading score and still have empty slots in a train. By contrast, slot efficiency does reflect the presence of empty slots as well as consider the improper matching of cars with loads:

$$\text{Slot Efficiency} = \frac{30(2 \times 20 \text{ ft} + 40 \text{ ft} + 53 \text{ ft} + 48 \text{ ft} + 53 \text{ ft})}{30(6 \times 53 \text{ ft})} \quad (3.8)$$

$$\text{Slot Efficiency} = 73.6\%$$

The empty top position in the middle well and the 40-ft international containers in the 53-ft well-car slot contribute to the lower slot efficiency score. The empty slot in well C, as well as the larger gaps between wells A and B, cause the train's aerodynamic coefficient to be 12.82 lb/mph², which is a very high coefficient (a 7,500-foot intermodal train's coefficient ranges from 9 to 13 lb/mph² under normal operating conditions). In the following sections, I describe variations of this scenario in which the train's loading is incrementally altered to show how the loading performance scores and the drag coefficient change as a function of loading. Specifically, I consider three variations of Scenario A: adding a 53-ft container to empty slots, replacing loads in well A with 53-ft containers, and replacing all loads with 53-ft containers.

3.6.2 Variations of Scenario A

3.6.2.1 Adding 53-ft Containers to Empty Slots

For the first scenario, the empty slot in the top middle well is loaded with a 53-ft container. These empty slots are filled incrementally starting in the front and then moving towards the back of the train. This results in an incremental improvement in all the metrics' scores and the aerodynamic coefficient as empty slots are filled (Figure 3.4). Notice that the improvement is the same for slot utilization, slot efficiency, and TFPU.

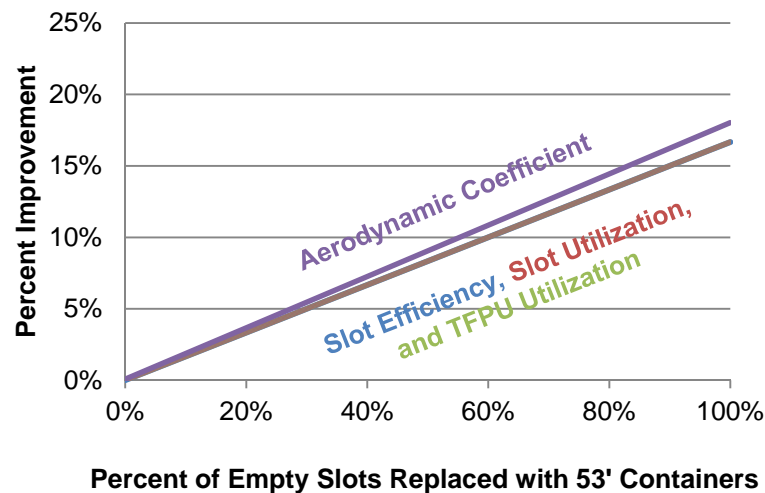


Figure 3.4 Improvement in loading performance and aerodynamics by replacing empty slots with 53-ft containers

The improvement in the aerodynamic coefficient can be determined using the following equation:

$$\text{Improvement in Aerodynamic Coefficient} = \frac{C_o - C_j}{C_o} \quad (3.9)$$

Where:

C_o = aerodynamic coefficient for the base case

C_j = aerodynamic coefficient after improving the loading of the j th slot in the train

The loading metrics have differing y-intercepts but their rate of improvement is the same (Figure 3.5).

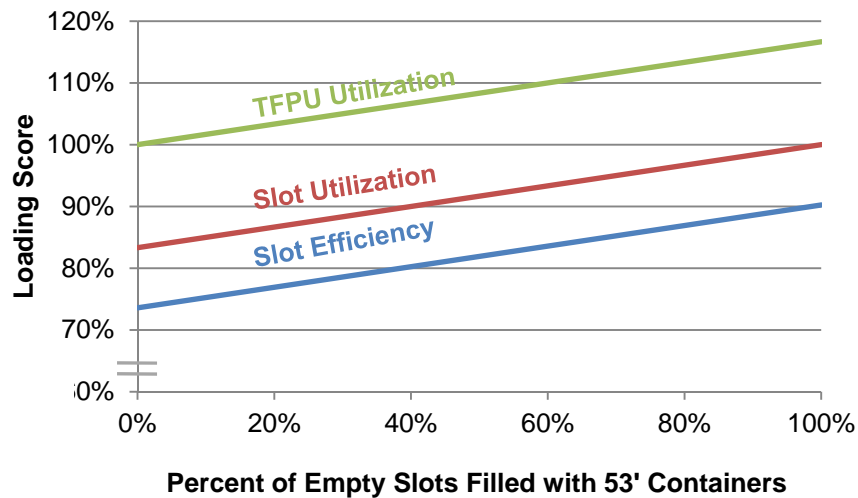


Figure 3.5 Improvement in loading score as empty slots are replaced with 53-ft containers

Note that this method of determining the improvement in the aerodynamic coefficient in Equation 3.9 will be used for all scenario variations in this chapter.

In Figure 3.4, the addition of 53-ft containers to the train's empty slots improves the aerodynamic coefficient by 16.67%. However, if the size of the added load changes, the slot efficiency improvement will not be as great. For instance, if a 40-ft container was added to empty slots instead of a 53-ft container, the improvement in the slot efficiency score would be 0.42% per load added while the other loading metric improvements would not change in comparison to the 53-ft case. Another interesting case is adding two 20-ft containers to the middle well and moving the 53-ft container from the bottom slot to the top. In comparison to the addition of 40-ft containers, the only metric that would behave differently is TFPU utilization where its score would be improved 1.1% for each pair of 20-ft containers added to the train. From this analysis, each loading metric as well as the aerodynamic coefficient improves as more empty slots are filled with loads.

3.6.2.2 Replacing Loads in Well A with 53-ft Containers

The next variation was developed to observe how the loading metrics adapt to increasing the load lengths from 40-ft to 53-ft. Specifically, I consider how the loading performance changes when the 40-ft containers and the pair of 20-ft containers are switched to 53-ft containers (Figure 3.6). The incremental improvement is as follows:

1. Exchange a 40-ft container on the top of well A for a 53-ft container
2. Exchange the two 20-ft containers on the bottom of well A to a 53-ft container
3. Repeat steps 1 and 2 for the other 29 railcars in the train, from front to rear

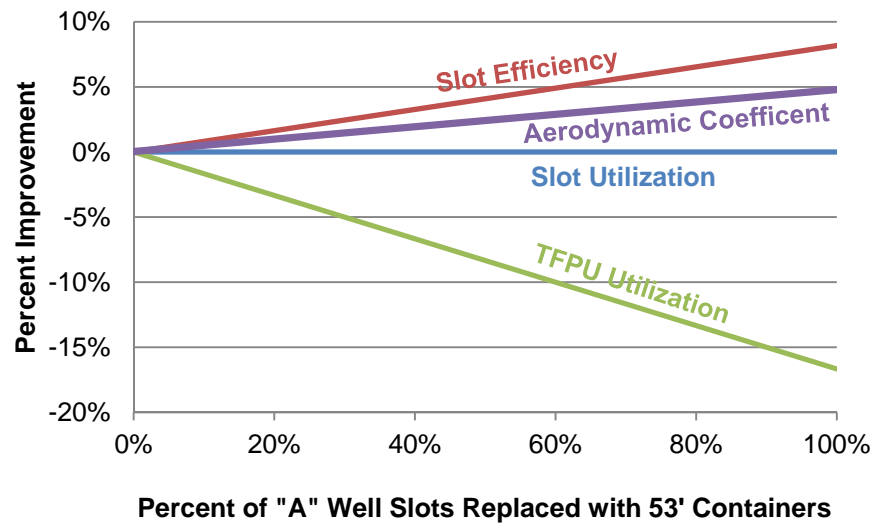


Figure 3.6 Improvement in loading score as international loads in well A are changed to 53-ft containers

Replacing 20-ft and 40-ft containers with 53-ft containers did not affect slot utilization and reduced the TFPU utilization score. The aerodynamic improvement is less than adding containers in the middle car's empty slot, but it can still be useful in improving an intermodal train's energy efficiency. Therefore, an increase in load size was detrimental to TFPU utilization, but improved slot efficiency and the aerodynamic coefficient, and had no effect on slot utilization.

3.6.2.3 Replacing All Loads with 53-ft Containers

The final variation is combining the previous two variations to include replacement of empty slots and increase the size of all loads to 53-ft containers. The order in which the railcars are replaced is as follows:

1. Exchange the 40-ft container in the top slot of well A with a 53-ft container
2. Exchange the two 20-ft containers in the bottom slot of well A with a 53-ft container

3. Add a 53-ft container in the top slot in well C
4. Exchange the 48-ft container in the bottom slot of well B with a 53-ft container
5. Repeat steps 1 to 4 for the other 29 cars, from front to rear

The combination of filling empty slots and exchanging smaller loads for 53-ft containers results in increased slot utilization and slot efficiency, and an improvement in the train's aerodynamic coefficient (Figure 3.7).

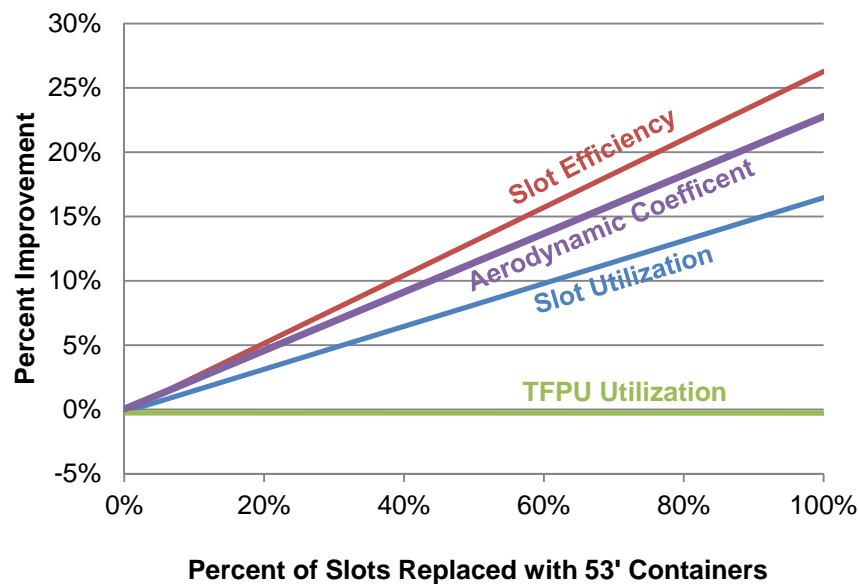


Figure 3.7 Improvement in loading score as all loads are changed to 53-ft containers

TFPU utilization remains unchanged at 100%, while slot efficiency and slot utilization reach 100% as all 120 slots are filled and/or replaced with 53-ft containers. This final scenario resulted in an aerodynamic coefficient of 9.91 lb/mph² whereas filling empty slots had an aerodynamic coefficient of 10.51 lb/mph² and increasing load size had a coefficient of 12.21 lb/mph². Therefore, from an aerodynamics standpoint, it is more important to fill empty slots than to try

and increase the size of loads within the train consist. The aerodynamic coefficients and the loading scores for Scenario A and its variations are summarized in Table 3.1.

Table 3.1 Scenario A Summary

Description	Slot Utilization	TFPU Utilization	Slot Efficiency	Aerodynamic Coefficient (lb/mph ²)
Base scenario	83%	100%	74%	12.82
Replace empty slots with 53-ft containers	100%	117%	91%	12.51
Replace loads in well A with 53-ft containers	83%	83%	82%	12.21
Replace all loads with 53-ft containers	100%	100%	100%	9.91

3.6.3 Analysis of Scenario B: Trailers on Spine Car

For the spine car scenario, all three slots have at least one load, thus the slot utilization is 100%. For TFPU, assuming that the railcar length is 189.5 ft (four loads at 189.5 ft) the actual TFPU would be:

$$\begin{aligned}
 \text{Actual TFPU} &= \frac{30 \times 189.5 \text{ ft}}{30 \times (2 + 1 + 1) \text{ loads}} \\
 \text{Actual TFPU} &= 47.38 \text{ ft/load}
 \end{aligned}
 \tag{3.10}$$

If the ideal TFPU is assumed to be 63.17 ft/load, which is one third of the railcar length, the TFPU utilization is 133%. The score is greater than 100% because of the two 28-ft trailers in platform A. Assuming the ideal load length for each platform is 57 ft, the train's slot efficiency is:

$$\text{Slot Efficiency} = \frac{30(2 \times 28 \text{ ft} + 28 \text{ ft} + 48 \text{ ft})}{30(3 \times 57 \text{ ft})} \quad (3.11)$$

$$\text{Slot Efficiency} = 77.19\%$$

The aerodynamic coefficient for the train is 9.09 lb/mph² and this will be the base value for comparison of the three variations of Scenario B that consider: adding a 28-ft trailer to platform C, replacing the 28-ft trailer in platform C with a 53-ft trailer, and converting all platform loads to 53-ft trailers.

3.6.4 Variations of Scenario B

3.6.4.1 Adding a 28-ft trailer to Platform C

For the first scenario modification, a 28-ft trailer is added to platform C (Figure 3.8). Each 28-ft trailer adds 1.11% to the TFPU utilization score and a 0.55% increase in slot efficiency. However, slot utilization does not change because all slots in the train remain filled. Looking at the reduction in the aerodynamic coefficient, there is a 0.65% improvement in the coefficient as 28-ft trailers are added to the train. In this case, the aerodynamic improvement most closely follows the improvement in the slot efficiency.

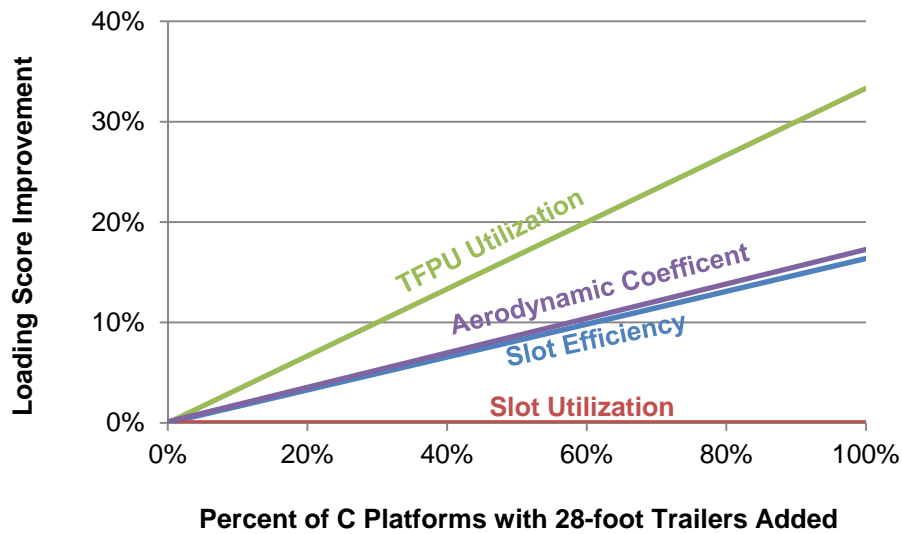


Figure 3.8 Improvement in loading score as 28-ft trailers are added to the train

3.6.4.2 Replacing the 28-ft trailer in Platform C with a 53-ft trailer

The second variation of Scenario B is replacing the 28-ft container in platform C with a 53-ft trailer. Replacing trailers does not affect the slot utilization and TFPU utilization scores. The only score that changes is slot efficiency, which improves by 0.43% per 28-ft trailer replaced (Figure 3.9). The aerodynamic coefficient has a slightly higher rate of improvement than slot efficiency. Compared to the previous variation, the addition of a 28-ft trailer results in a somewhat higher improvement in aerodynamics than switching to a 53-ft trailer.

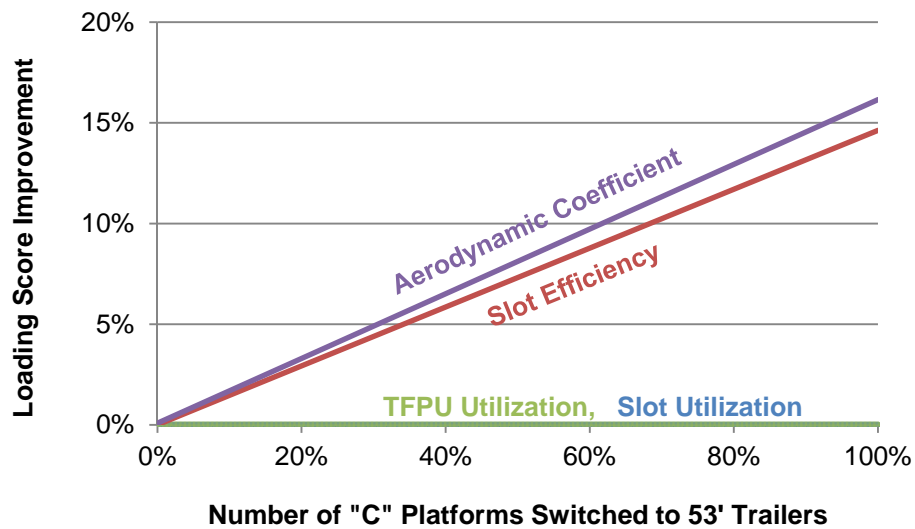


Figure 3.9 Improvement in loading score as the middle platform is changed to a 53-ft trailer

3.6.4.3 Replacing all platform loads with 53-ft trailers

Similar to the last variation of Scenario A, all loads on the platforms will be switched to 53-ft trailers. The replacement order is as follows:

1. Exchange two 28-ft trailers on platform A for a 53-ft trailer
2. Exchange a 28-ft trailer on platform C for a 53-ft trailer
3. Exchange a 48-ft trailer on platform B for a 53-ft trailer
4. Repeat steps 1 to 3 for the other 29 cars in the train, from front to rear

Figure 3.10 shows how the metrics and aerodynamics change as train loading changes from front to rear. Replacing all the loads with 53-ft trailers provided a 16.6% reduction in the train's aerodynamic coefficient or a 0.18% reduction per platform. This exchange also improved the slot efficiency score by 15.79%. TFPU utilization decreases because the two 28-ft trailers are replaced with one trailer. The lowest aerodynamic coefficient attained by adding 28-ft trailers was 7.52 lb/mph² and is close to the aerodynamic coefficient of 7.58 lb/mph² when all platforms

have 53-ft trailers. Like Scenario A, filling large empty spaces in the train with loads is more beneficial than changing load sizes in terms of train aerodynamics and slot efficiency (Table 3.2).

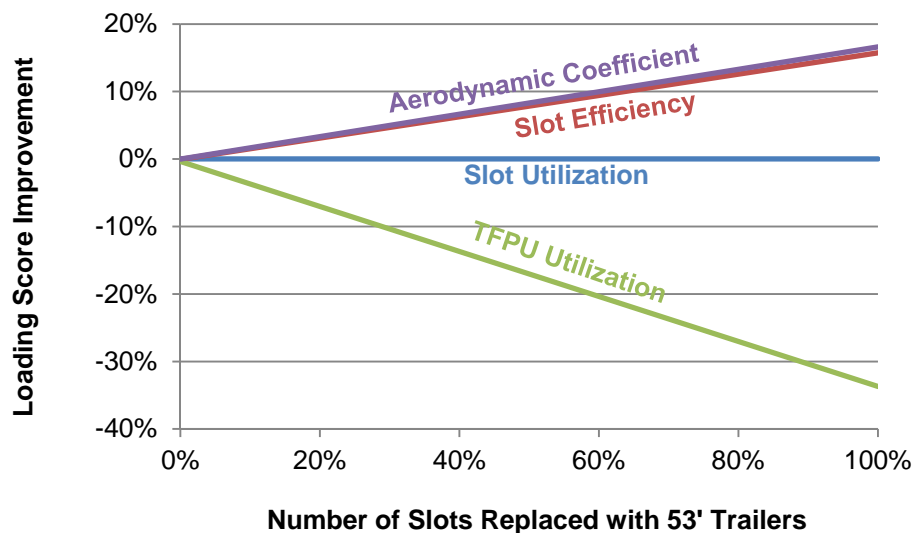


Figure 3.10 Improvement in loading score as all platforms are replaced with 53-ft trailers

Table 3.2 Summary of Scenario B Improvements

Description	Slot Utilization	TFPU Utilization	Slot Efficiency	Aerodynamic Coefficient (lb/mph ²)
Base scenario	100%	133%	77%	9.09
Add a 28-ft trailer to platform C	100%	171%	94%	7.52
Replace the 28-ft trailer in platform C to a 53-ft trailer	100%	133%	92%	7.62
Replace all loads with 53-ft trailers	100%	100%	93%	7.58

3.6.5 Analysis of Case Study Results

Both the well car and spine car scenarios show that slot efficiency is a better indicator of the aerodynamic efficiency compared to TFPU and slot utilization. However, slot efficiency fails

to distinguish between empty slots and larger load sizes and does not characterize the position-in-train aerodynamic effects. Wind tunnel testing has shown that the lead locomotive experiences the highest aerodynamic drag, and the drag then declines for about the next ten units in the train with the remaining units in the train having relatively constant aerodynamic drag (Gielow and Furlong 1987, Engdahl 1987). Therefore, loads added in the back of the train have less effect on aerodynamic drag reduction than ones added in the front, even though the effect on slot efficiency would be the same. A way to encourage that loading improvements occur at the front of the train first would be to assign coefficients to each position in the train. The coefficients would be larger for the first ten units and smaller for units in the back of the train. The optimization model formulated by Lai et al. (2007) considered the unit's position in the train by using an adjustment factor developed from wind tunnel testing by Engdahl (1987). This adjustment factor is calculated as follows:

$$A_k = \frac{14.85824e^{-0.29308k} + 9.86549e^{-0.00007k} + 10.66914}{14.85824e^{-0.29308k_Q} + 9.86549e^{-0.00007k_Q} + 10.66914} \quad (3.12)$$

Where:

A_k = the adjustment factor for the k th unit in the train

k = unit position in the train

k_Q = last unit position in the train

Adding this adjustment factor to the slot efficiency equation yields the following modified equation:

$$\text{Modified Slot Efficiency} = \frac{\sum_{k=1}^N A_k \frac{(l_k + l_k^* d_k)}{(t_k + t_k^* d_k)}}{\sum_{k=1}^N A_k} \quad (3.13)$$

Where:

A_k = the adjustment factor for the k th unit in the train

N = total number of units in the train

d_k = binary variable that is equal to one when the slot has double stack capability and zero when the slot only has single stack capability

l_k = actual load length for unit k

l_k^* = actual load length for the top load in unit k

t_k = ideal load length for unit k

t_k^* = ideal load length for the top load in unit k

The case studies of the scenarios described here illustrate how various changes in train loading patterns improve aerodynamics, especially by filling empty slots. These changes include increasing trailer or container size, filling empty slots, and matching loads. However, these improvements may be constrained by several factors at the terminal that are outside of the terminal manager's control.

3.7 POTENTIAL IMPACT ON TERMINAL OPERATIONS

From a terminal operations perspective, there are some limitations in the ability to consistently achieve high slot efficiency and reduced aerodynamic resistance. These include load availability, railcar availability, time constraints, terminal parking space, and maintaining high customer satisfaction by ensuring on-time arrivals. Some of these constraints

are interrelated.

3.7.1 Load and Equipment Availability

A train made up of several blocks bound for different destinations may include blocks that are more highly used than others. The use of each block is dependent on the customer demand for the destination location. Some destinations may require larger blocks or more frequent service than others. The block size can be estimated by looking at historical data to predict the number of loads for that destination and the block size needed. To eliminate empty slots, the number of railcars in the block or the frequency of service could be reduced. However, this could lead to other negative impacts on terminal performance, especially customer service quality if there is a shortage of slots on a train.

Terminal managers often have to use railcars from inbound trains to make up the blocks for outbound trains, even if the slots or platforms are not optimal for the outbound loads. Also, outbound trains may include less efficiently loaded railcars because the destination terminal is short on railcars so they are being transferred to meet that terminal's need. Railcars with larger platform or well sizes, such as 53-ft well cars or 57-ft spine cars offer great flexibility to terminals than cars with smaller platforms or well lengths because they can accommodate all possible standard trailer and container sizes. The flexibility offered by larger-sized well and platforms also means that less switching is needed, so terminal operating efficiency would also be improved.

3.7.2 Dwell Time and Traffic Flow

There is uncertainty in the number and distribution of load types that will arrive at a terminal. In order to maximize a train's loading efficiency, a terminal manager might wait to start loading a train to allow more loads to arrive. This provides a larger pool of loads to choose from and increases the likelihood of optimizing load placement on the train. However, this also may increase load dwell time and exceed the terminal's load storage capacity. Some terminals have little or no extra storage space for arriving loads resulting in quick decisions about load placement on a train. Also, the load arrival rate varies through the day, although the peak hours and days of the week are generally predictable based on historical data. The ability to optimize loading on peak traffic days may vary through the week, depending on the volume of traffic and degree of terminal congestion.

3.7.3 Customer Service Performance

If terminal employees wait too long to begin placing loads on a train, they may not have enough time to load all the containers or trailers before the cut-off time, so this scenario must be avoided. Having a load miss the cut-off time when there was space and opportunity to load it onto the train is unacceptable from a customer service standpoint. However, because fuel is the highest operating cost for railroads, a reduction in fuel consumption through improved loading practices may be worth some increase in dwell time spent in the terminal. The fuel savings would reduce costs and could benefit customers if a portion of these savings were passed on to them.

3.8 FUTURE WORK

Minimal changes in loading practices could result in substantial savings due to improved train aerodynamics and consequent reduced fuel consumption. Important questions remain regarding how to optimize the balance between minimizing the impact of improved intermodal train loading practices on terminal operations, versus providing the benefit of the aforementioned fuel savings. Radio frequency timestamp data from several intermodal terminals are being used to study the motion of containers and trailers through terminals (Chapter 5). This will help evaluate if and to what extent dwell time is affected by use of loading practices intended to improve train aerodynamics. This study may also help identify sources of avoidable waste in terminal operations and loading for lean improvements. It will also provide a better understanding of why poor aerodynamic loading may occur.

3.9 CONCLUSION

Loading metrics can help terminals make up more energy-efficient train consists and facilitate loading improvements. Of the three metrics considered here, slot efficiency best accounts for the aerodynamic improvements associated with matching loads to the right well or platform size. If the negative impacts to terminal operations due to changing loading practices are minimized and other energy efficiency improvements, such as more fuel-efficient locomotives, improved train handling, and improved railcar design, are considered, there may be a number of operating scenarios in which fuel savings are possible.

CHAPTER 4: MONITORING THE AERODYNAMIC EFFICIENCY OF INTERMODAL TRAIN LOADING USING MACHINE VISION

(Modified based on paper published in Proceedings of Transportation Research Board Annual Conference, Washington D.C., January 2011)

4.1 INTRODUCTION

Intermodal freight transportation generates one of the largest sources of revenue for North American railroads. In May of 2011, North America intermodal traffic volumes were at 932,956 trailers and containers originated, which is up 7.5% from May of 2010 (Truckinginfo 2011), and further growth in intermodal traffic is expected to continue for the foreseeable future.

Intermodal trains are more energy efficient than truck transport because they capitalize on several efficiencies inherent to rail transport. These include their low-friction steel wheel-on-steel rail interface, rolling stock capable of transporting multiple trailers or containers, and the use of trains in which railcars are closely coupled therefore offering less aerodynamic resistance. Despite their energy efficiency relative to trucks, intermodal trains are less efficient than their bulk freight counterparts. Improving intermodal train energy efficiency can reduce fuel costs which represents one of the largest components of Class I railroads' annual operating expense. In 2007, Class I railroads spent \$12.2 billion on fuel, representing 25.8% of their total operating cost (AAR 2009).

Currently, most railway intermodal loading methodologies encourage terminal managers to load trains in a manner that maximizes intermodal equipment utilization. Alternatively, adopting a loading protocol that matches containers and trailers to their appropriate rolling stock capacity (e.g. slot length) to minimize gaps between loads can reduce the aerodynamic resistance for intermodal trains. To evaluate the feasibility of improving intermodal train loading operations, the BNSF Railway is funding research at the University of Illinois at Urbana-Champaign (UIUC) with the objective of developing a machine vision system to automatically

analyze the aerodynamic efficiency of intermodal train loading by measuring the positioning of loads and gaps between loads.

4.2 INTERMODAL TRAIN AERODYNAMICS AND ENERGY EFFICIENCY

North American intermodal rolling stock consists of flat cars, spine cars, and well cars. These cars have a variety of designs and loading capabilities that result in varying gap lengths between loads on adjacent railcars or platforms/wells. Previous research has found that when gaps between loads exceed 6 feet (ft), the loads are aerodynamically distinct and the drag increases substantially. Although some combinations of intermodal rolling stock are closely spaced, others are constrained by design to have large gaps (Lai and Barkan 2005). In some cases, however, railroads can affect gap length by how they match loads to cars. Intermodal freight trains are among the fastest freight trains in North America often operate at speeds up to 70 miles-per-hour (mph). This is necessary to remain competitive with highway truck transport, which offers the principal competitor for the traffic these trains handle. As a consequence the aerodynamics of intermodal trains are particularly important.

4.2.1 Train Resistance

Train resistance is the summation of frictional and other forces that a train must overcome in order to move (Hay 1982). The general equation for train resistance is $R = AW + BV + CV^2$, where R is total train resistance, A is bearing resistance, B is flange resistance, and C is aerodynamic resistance (Hay 1982). The A term varies with the weight (W) of the railcar or train, the B term varies linearly with train speed (V), and the C term increases exponentially with train speed. Due to the exponential nature of the aerodynamic resistance term, methods of

reducing it have a particularly important impact on overall train resistance and warrant further study. Aerodynamic drag reduction can take several forms including redesign of intermodal rolling stock, installing aerodynamic reduction attachments, container and trailer design improvements, and improved loading practices. This latter option provides an economical alternative to redesigning railcars or containers and trailers, which requires significant capital investment and design considerations regarding compatibility with existing container and trailer types.

4.2.2 Optimizing Train Loading Using Loading Metrics

The most common intermodal train loading metric is *slot utilization*. In slot utilization, the number of loads on an intermodal train is maximized, with the objective of filling all available slots. This method does not require minimization of the gaps between adjacent loads, since the objective of slot utilization is only to ensure that all slots are used for loads that are equal to, or longer than the slot's length. An alternative measure to evaluate intermodal loading and minimize gaps between adjacent loads is *slot efficiency*. Slot efficiency maximizes the utilization of slots on the train as well as minimizing the gaps between loads. In other words, the number of containers and trailers per unit length of train is maximized. Lai and Barkan (2005) compared the benefits of slot efficiency and slot utilization. The potential savings from switching from 100% slot utilization to 100% slot efficiency can be as much as 1 gallon of fuel per mile, depending on the specific rolling stock and loads available (Lai et al. 2007b). Additionally, Lai et al. (2007a) developed an optimization model that minimized a train's gap lengths given specified loads. Lai et al. (2008) expanded the earlier optimization model to account for loading multiple trains simultaneously and the uncertainty of incoming loads at a

terminal. In order to help railroads monitor intermodal terminal loading performance, UIUC has been developing a machine vision system that will automatically record and analyze train loading practices (Lai et al. 2007b).

4.3 MACHINE VISION SYSTEM DEVELOPMENT

A typical machine vision system acquires images from a digital camera and processes these images using computer algorithms with the objective of extracting pertinent information. The algorithms, which are the core of the machine vision system, transform or manipulate images to obtain objective and potentially quantifiable results by using the color, texture, geometry, and other attributes of interest within the image (Shapiro and Stockman 2001).

4.3.1 Machine Vision Technology in the Railroad Industry

Since the 1980s, machine vision technology has been used to improve railroad safety, efficiency, and reliability through inspection systems that address both civil infrastructure and rolling-stock mechanical components (Steets and Tse 1998, Hart et al. 2004, Lundgren and Killian 2005, Yella et al. 2008, Schlake et al. 2010, Resendiz et al. 2010). The uniform shapes and sizes of intermodal containers and trailers make machine vision a viable technology for evaluating intermodal train loading configurations.

4.3.2 Wayside Machine Vision System Objectives

To capture images and perform aerodynamic analyses for each passing intermodal train, a wayside machine vision system must be designed with the computational capability to capture, store, and analyze videos with near real-time performance. This is best accomplished through

the construction of a permanent, automated facility with multiple processors. UIUC is developing such a system at a site along BNSF's Southern Transcon intermodal corridor. The design objectives for this installation includes the following:

1. Automate the video capture and data analysis system.
2. Determine the type of each intermodal load (single or double stack container or trailer) and measure its length.
3. Consistently and accurately determine slot efficiency and the train's aerodynamic coefficient based on the gap measurements and comparisons of the well or platform size.
4. Provide useful results that can be interpreted by intermodal terminal and transportation managers and applied toward improving loading operations.

4.4 WAYSIDE SUB-SYSTEMS

To achieve the aforementioned goals, the machine vision system has been designed with several sub-systems that are integrated through customized automation software. These sub-systems include wayside automation, video acquisition, load monitoring, train scoring, and communications. The wayside automation system detects trains approaching the wayside installation, prepares the system for video acquisition, collects automatic equipment identification (AEI) data, and executes software algorithms with corresponding results from the other sub-systems. AEI data contains the order of rolling stock within the train consist and provides a timestamp for each locomotive and railcar axle. The video acquisition system collects and stores videos, and the Train Monitoring System (TMS) analyzes these videos to determine the train's particular loading. The Train Scoring System (TSS) uses information about the

loading configuration from the TMS and AEI sub-systems to score the train on how efficiently it is loaded. The communication system provides a means to interact with and monitor the performance of the system and ultimately transmit the results to intermodal terminal managers and other personnel. The following sections of this chapter describe each of the machine vision sub-systems.

4.4.1 Wayside Automation System

A wayside automation system was developed to integrate each of the sub-systems into a single system (Figure 4.1). For a wayside installation, the automation system includes various train detectors, signal acquisition electronics, and train detection logic for interpreting the signals and initiating subsystem operations (Figure 4.2). When the system is idle, it waits for a pulse from a detector signal indicating an approaching train. Once a train activates a detector (Figure 4.1), the system initiates several steps and then begins video recording. The recording continues until the train clears all of the detectors. After the video is stored, the computer resumes waiting for another train. Within the automation system, there is a contingency for the rare case in which a train stops at the installation, which will pause the video recording. If the signals from the detectors indicate that the train is moving, the system will resume video recording. Whenever the system is idle, it analyzes videos to determine the loading configuration using TMS and then calculates the trains' aerodynamic coefficient and slot efficiency using TSS.

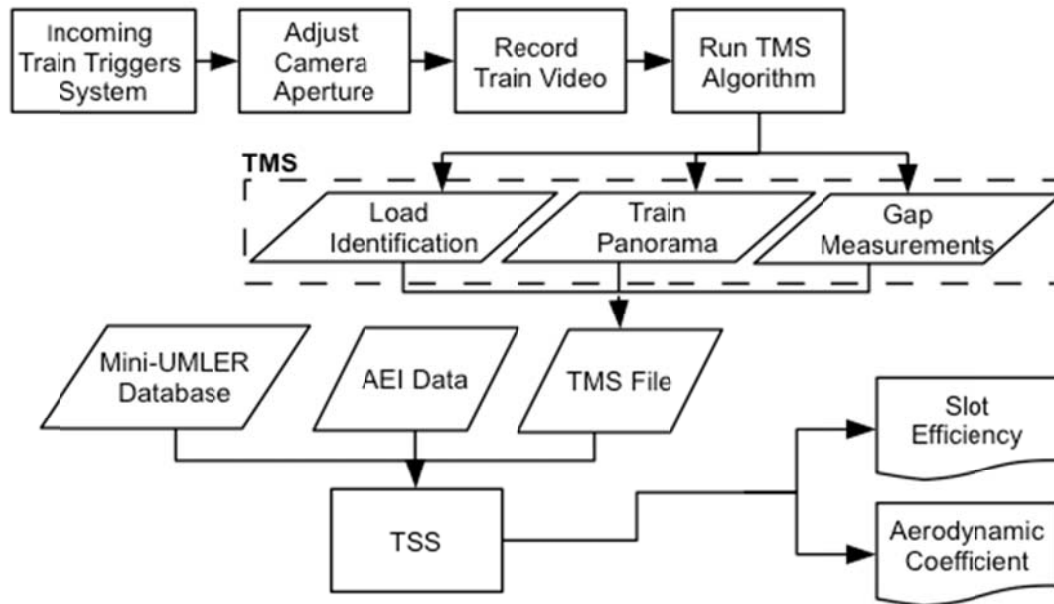


Figure 4.1 Flow chart of the machine vision automation system and sub-systems

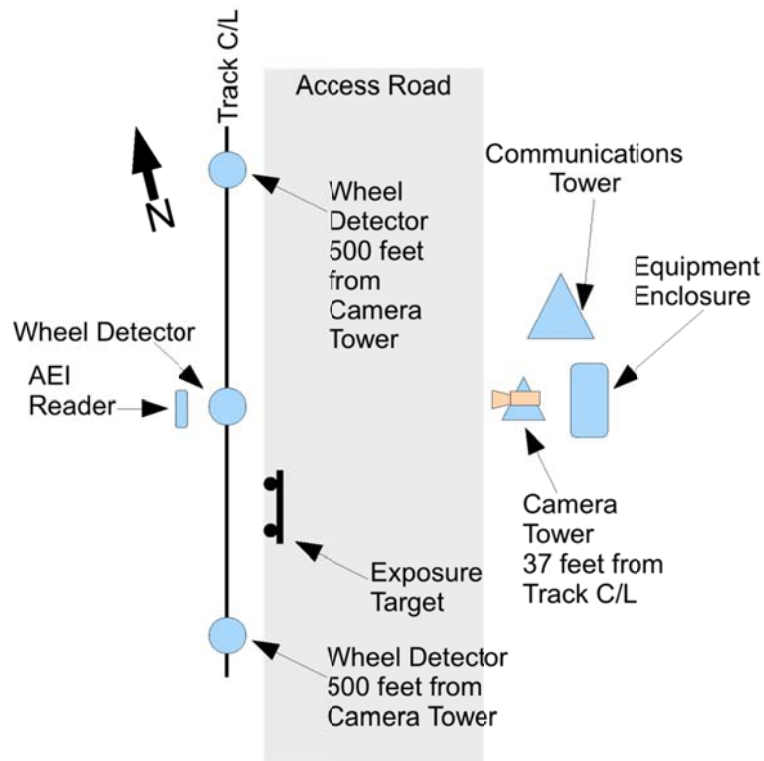


Figure 4.2 Installation layout of the prototype wayside machine vision system at BNSF's Logistics Park Chicago (LPC)

4.4.2 Image Acquisition System

The image acquisition sub-system provides methods for capturing usable images. If images are not properly acquired (e.g. appropriate view, proper exposure, etc), little or no useful information can be extracted. To properly acquire images, the equipment must be capable of capturing videos and be able to adjust to varying environmental conditions. The major factors affecting the acquisition of suitable images suited for this project are described in the following sections.

4.4.2.1 Camera Placement and Orientation

Camera placement and orientation are important considerations when designing the image acquisition system. The optimal location of the camera depends on what object the camera is required to observe and the specific information that needs to be obtained from the images. For detecting intermodal loads, the camera is aligned so it is normal to the side of the train. This is accomplished by adjusting the pan, tilt, and “dutch” tilt of the camera mount beneath the camera and ensures that the train will not be distorted in any direction (Rickett 2011). If the image of the train is too distorted, the TMS algorithms will not function properly. Also, the camera setup needs to be placed where there are no obstructions in the camera view, such as another train travelling in front of or behind the train to be recorded. Finally, the camera is oriented so that the top of double stack containers are clearly visible and such that barrel distortion near the top of the image is minimized. Increasing the lens focal length reduces barrel distortion, which results in a better quality at the edge of the image, and increases the distance needed to acquire the initial image width (Freid et al. 2007).

4.4.2.2 Video Image Acquisition

Recording videos 24 hours a day in an outdoor setting requires careful consideration of image exposure. Image exposure depends upon the light from the sun and the weather conditions present at the time of the recording. This is also complicated by the need to record images of the background prior to the arrival of the train, so that it can be more easily removed from the individual images (see Section 4.4.3.1).

One approach to achieving proper exposure is to use an exposure target near the track in the camera's field of view. This target is designed and positioned to reflect light in the same manner as the side of a passing train. When the detector indicates an approaching train, the camera reduces its field of view (FOV) to the area of the target and adjust all of the camera parameters (with the exception of shutter speed) to obtain a properly-exposed image. The shutter speed setting is constrained so that train movement does not blur the image; shutter speed setting also depends upon the intensity of light (Freid et al. 2007). Ideally, there is a good amount of light so that the shutter speed can be increased to minimize blurring of the image (Freid et al. 2007). Once this set of parameters is adjusted for the current conditions, the FOV is returned to the entire image, and the system awaits the train. Just before the train enters the camera's FOV, wheel detectors initiate recording the background entry of the train, and continues recording until the entire train has passed. The machine vision algorithms can remove the background of properly exposed video images leaving just the images of the train, which leads to the next step in the process, assessing its loading configuration.

4.4.3 Train Monitoring System

This section describes the Train Monitoring System (TMS) that uses image processing algorithms to analyze intermodal train videos (Figure 4.3). The first step is to identify the train in each image frame of the video using a background removal algorithm. Then a panorama of the entire train is created to detect intermodal loads and the gaps between them.

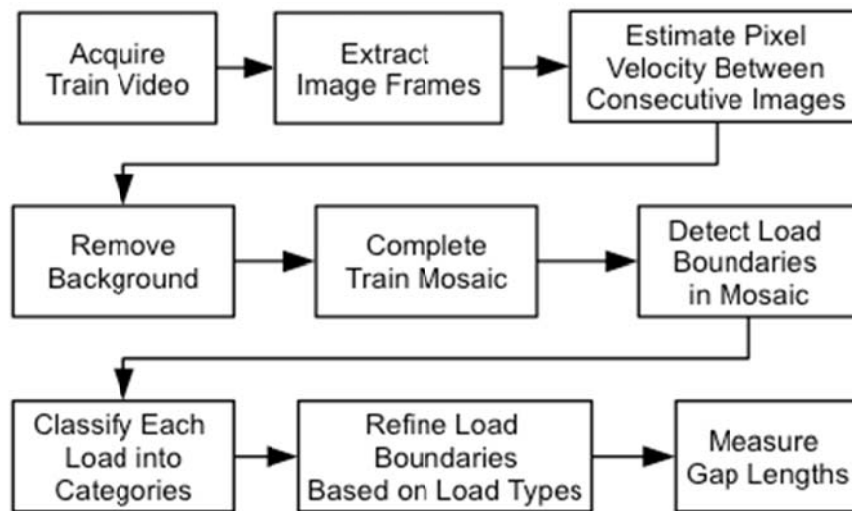


Figure 4.3 Flow of Train Monitoring System starting with acquisition and ending with calculation of the gap lengths between loads

4.4.3.1 Background Removal

Background removal refers to the identification of objects of interest and the elimination of all other objects from a given image frame. All of the objects of interest are termed as “foreground” and everything else is termed as “background.” For this system, all the moving objects (i.e. the locomotives, railcars, and intermodal loads) form the foreground and the more static objects (e.g. the ground, trees, clouds, etc.) form the background. Thus, the TMS must correctly identify the foreground objects using their distinct characteristics (e.g. shape and

motion) to extract them from all other background objects. While this is being computed on each image frame of the video, the foreground objects are assembled, section-by-section, into a train panorama.

One specific characteristic of foreground objects is their considerable movement between consecutive frames as compared to objects in the background, which have negligible motion. This property can be utilized to distinguish and classify objects into foreground and background categories in a given image frame extracted from a train video. For example, suppose the current image frame requiring background removal is I_c . Let I_p and I_n denote image frames captured before and after I_c . Using a railcar visible in consecutive image frames, an initial estimate of the velocity of the train can be obtained by correlating the railcar in I_c and I_n or I_c and I_p . The initial velocity estimate, v , indicates the number of pixel shifted per consecutive image frame for the objects in the scene. A coordinate system is defined with its origin lying at the bottom left corner of an image where the horizontal direction is along the x -axis and the vertical direction is along the y -axis. Once the initial estimate of v is obtained, the next step is to find regions moving at velocity v in the current image frame (I_c). These regions are found by taking a window of size S_z (21 x 41 pixels) in image frame I_c at any location (x,y) and correlating it with a window of similar size in image frame I_p at location $(x-v,y)$ and at location $(x+v,y)$ in I_n . The above calculation assumes that the train only moves horizontally, which is reasonable as there is only a sub-pixel order of vertical movement between any pair of consecutive image frames. The correlation used is known as normalized cross correlation (NCC) (Lewis 1995). In this correlation technique, the mean pixel intensity of the image frame window is first subtracted from each pixel value in the window to reduce the effect of small lighting changes. Next, all the pixel values in the window are normalized such that their sum of squares is equal to one.

At each window patch located at (x,y) in I_c , two NCC costs are obtained, NCC_p and NCC_n , corresponding to correlations with previous (I_p) and next image (I_n) frames. In addition to these two correlations, the current I_c window is also correlated with the current background estimate. This allows for static objects in the scene to correlate with high confidence. This value is stored as NCC_{bg} . Finally, all the values are combined together to obtain a foreground value referred to FG_{Cost} as follows:

$$FG_{Cost} = \frac{(NCC_p + NCC_n - 2 \times NCC_{bg})}{4} \quad (4.1)$$

The denominator normalizes the FG_{Cost} between negative one and positive one. This foreground cost is then set as a threshold to obtain the foreground objects (Figure 4.4).

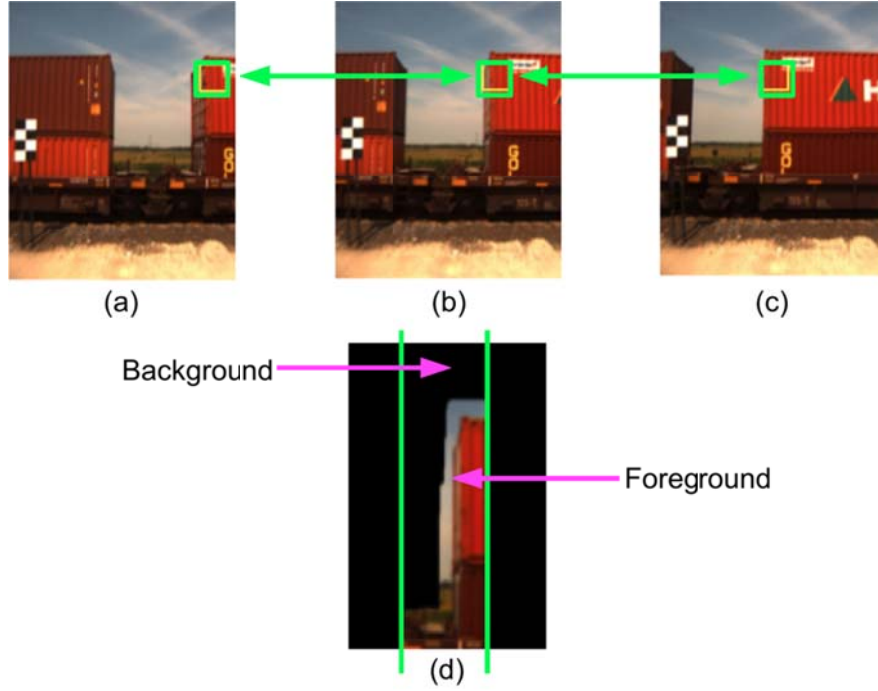


Figure 4.4 Normalized cross correlation calculated between image frames (a) I_p at $x-v$, (b) I_c at x , (c) I_n at $x+v$ and (d) the background removed from image I_c

4.4.3.2 Mosaic Generation and Load Detection

Once the velocity is obtained, strips having a width equal to the velocity v are taken from I_c and are used to create the panoramic image. This is continued for all the image frames in the video to develop a single panoramic image of the entire train with its background removed, is generated (Figure 4.5). Using the particular velocity calculated for that image frame ensures the panorama will not contain duplicate or missing parts of the train and makes the algorithm responsive to changes in train speed.

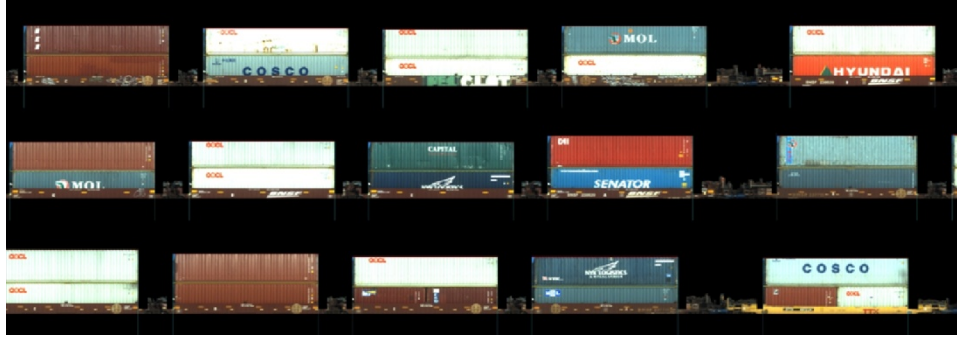


Figure 4.5 Three horizontal strips showing a portion of an intermodal freight train panorama

In the panorama, the gaps are detected by finding the edges of the containers and trailers. The containers are later classified as single or double stacked based on their height above the top of the rail. The different types of double-stack load configurations (e.g. a smaller container on top of a larger container and vice versa) are identified by detecting the presence of background at the edges of both the top and bottom containers. The trailers are classified by detecting the presence of background near the bottom of the trailer. The sizes of the loads are determined using a pixel-to-foot conversion determined by the camera and lens parameters and the location of the camera relative to the track. Once the container/trailer sizes and gap lengths between loads on the train are determined, the train's loading is then evaluated and scored by the Train Scoring System.

4.4.4 Train Scoring System (TSS)

The Train Scoring System (TSS) evaluates intermodal train loading efficiency and provides a train-specific aerodynamic coefficient using the gap-length information from the TMS. The aerodynamic coefficient can be used as a proxy for relative fuel consumption and results from the TSS will aid intermodal terminal managers in loading more fuel-efficient trains.

In order to attain these results, the TSS needs the following input data: certain parameters from the Universal Machine Language Equipment Register (UMLER) database pertaining to intermodal rolling stock, AEI data, and TMS result data. Figure 4.6 describes the flow of data through the major function of the TSS.

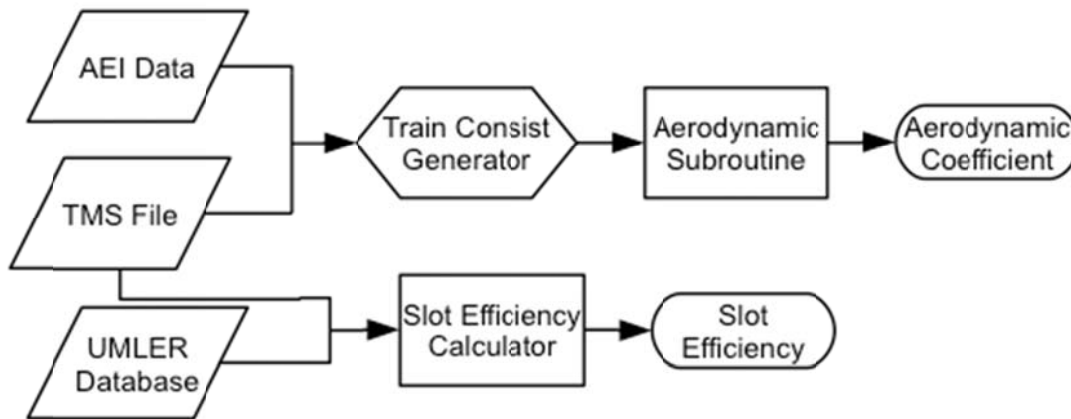


Figure 4.6 Flow Diagram of TSS beginning with the TMS (intermodal load analysis), AEI (intermodal equipment data), and the UMLER database (loading capability of intermodal railcars)

4.4.4.1 TSS Inputs

The UMLER database contains design and loading information on all railcars operating in unrestricted interchange in North America. UMLER data on reporting mark and car number, outside length, loading attributes, and other geometric and operational parameters are used. The loading attributes describe whether the railcar has one, three, or five units (the three or five-unit cars are articulated cars that are connected by drawbars or share trucks). Additional data fields describe whether the railcar can transport containers and/or trailers and what load sizes it can accommodate. The TSS uses the UMLER database to determine the ideal loading configurations for each railcar in the train. The second input is AEI data that includes the sequence of the railcars in the train and a timestamp for each axle. The axle timestamps help match the loads

identified in TMS with the correct railcar platform or well.

4.4.4.2 TSS Results Summary

The final result of the TSS is a text file that contains the slot efficiency for each slot in the train (for well cars, it includes both the bottom and top containers) and a value for the average slot efficiency for the entire train. The aerodynamic coefficient is also generated so the train's fuel consumption can be computed using the Train Energy Model (TEM). TSS output files are intended to be used to evaluate the loading performance of a particular terminal, train, and/or terminal manager.

4.4.4.3 Communication System

The communication system is a critical component in the machine vision system because it enables BNSF and UIUC to access the computer and monitor the system to ensure it is functioning properly. In the future, the results will be sent to the appropriate personnel at BNSF using the communication system, but they are presently being transferred manually using external data storage drives.

4.4.5 Wayside Installation Development

There are currently two field installations: one at BNSF's Logistics Park Chicago (LPC) facility in Joliet, Illinois and another revenue-service installation along BNSF's Southern Transcon near Kansas City, Missouri. While both installations have the same fundamental task, they differ in terms of their functionality and purpose. Both installations will be described in greater detail in the following sections.

4.4.5.1 Logistics Park Chicago (LPC) Test Installation Development

A semi-permanent wayside installation location was selected based on frequent

intermodal traffic and single-track operation, ensuring that no other trains would be visible in the background of the video. LPC was a good location for a test installation because approximately eight to ten intermodal trains pass by the site each day and it was located within an intermodal terminal providing easy access for developmental work and good security. Figure 4.2 shows the layout of the LPC installation.

For the image acquisition system, the camera was mounted inside a protective enclosure and connected to the computer via FireWire cable. The computer and the other hardware were stored inside a separate, aluminum enclosure to protect them from the elements. An exposure target was installed on the far side of the track, opposite to the camera was installed to enable proper adjustment of the camera. Wheel detectors were installed to signal to the computer to begin video recording when a train approached. A communication system allows video and AEI data to be transmitted over the internet for analysis on another (more powerful) computer. The LPC installation has an older AEI reader that converts the raw data into a format useable by TSS. This installation was useful to prove the feasibility of the wayside-installation concept and to test and develop the TMS background removal algorithms without the use of a backdrop. However, trains from LPC almost exclusively transport international containers thus the location does not reflect the variety of intermodal equipment rolling stock, units, and loading permutations experienced in revenue service. Consequently, a second installation was developed to analyze a large number of intermodal trains with all types of configurations and originating terminals.

4.4.5.2 Fully Automated Installation along BNSF's Southern Transcon

Currently, UIUC and BNSF are developing a fully automated wayside system along BNSF's Southern Transcon near Sibley, Missouri (Figure 4.7). This location has about 40 to 50 intermodal trains a day over one of the few remaining sections of single-track on the Southern

Transcon. Many of the intermodal trains travel to/from Chicago and Los Angeles and loading improvements on these trains would result in substantial fuel savings along this over 2,000-mile corridor.

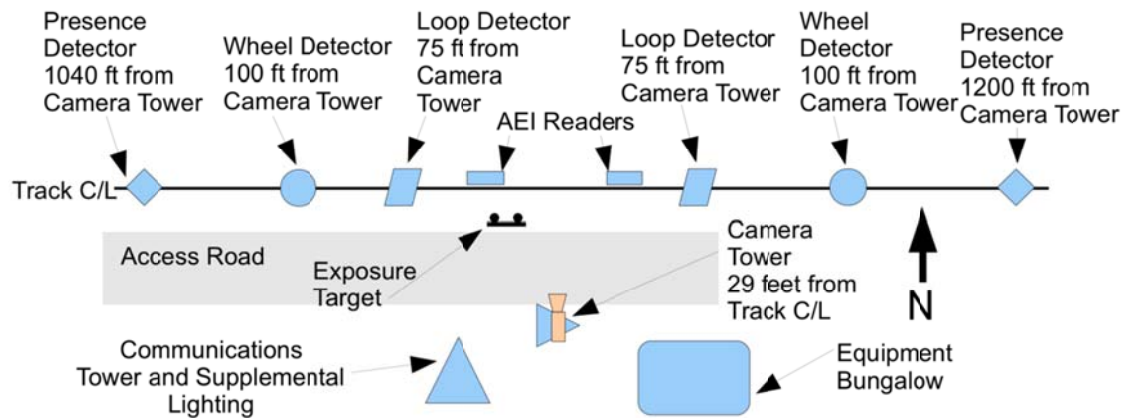


Figure 4.7 Installation layout of the BNSF Railway wayside machine vision system near Sibley, MO

The installation has three types of train detectors, each with different capabilities and functions. The presence detectors are located 1,040 ft west and 1,200 ft east of the camera tower. These detectors use microwave technology to detect trains and send a wireless signal to inform the system that a train is approaching. The wireless detectors also helped reduce installation costs for trenching cables along the BNSF right-of-way.

The wheel detectors, located 100 ft on either side of the camera, send a pulse to the computer when a locomotive or railcar wheel passes the detector. The inductive loop detectors, located 75 ft to either side of the camera, transmit a continuous signal if a train is occupying the loop detector circuit. The purpose of the loop detectors is to verify whether a train has stopped and there are no pulses from the wheel detector.

The installation at Sibley is similar to LPC in that it has a camera tower with an enclosure

to house the camera, a bungalow to house the computer and the other electronic equipment, and an exposure target. The installation also has artificial lights to enable video recording at night. Because some of the detectors outputs are not digital, a programmable logic controller (PLC) was installed to respond to various detector signals and control the current output of the lights.

The installation is capable of analyzing and scoring the train videos on-site. Currently, the communications system uses a USB internet modem with a small data upload and download allowance. Because of the small data allowance, videos are analyzed on-site or are transferred to external hard-drives and shipped to UIUC where the videos are analyzed and scored. In 2010, an AEI reader with redundant transponder detection capabilities was installed and integrated into the wayside automation sub-system.

4.5 FUTURE WORK

Currently, the TMS is undergoing testing using both video and AEI data from the wayside installation in Sibley. In addition, work continues on integration and testing of peripheral equipment and systems such as the artificial lighting and automated exposure adjustment under these conditions. Optimization of the TMS code is underway to achieve faster run-time while maintaining its current level of accuracy.

Additional research is underway to finalize methods for presenting intermodal loading results to BNSF in a manner conducive to improving their intermodal train energy efficiency. In the future, the aerodynamic coefficient from the machine vision system will serve as an input into TEM to compare the predicted fuel consumption to the actual fuel consumption along intermodal corridors. The use of TEM will also allow comparison of an optimally-loaded train's fuel consumption with that of a train less efficiently loaded. Additionally, fuel consumption

estimates can be validated through a comparative analysis of actual fuel consumption data and results obtained from the machine vision system and TEM.

In addition to analyzing TSS results, investigation continues on how the implementation of slot efficiency affects intermodal terminal operations. This will include a review of intermodal equipment utilization methods and load planning software used at railway intermodal terminals and port facilities (discussed in Chapter 3). In combination with machine vision systems for loading analysis, future research aims to help the railway industry improve intermodal train energy efficiency through the development of improved loading practices that minimize the effect on intermodal terminal operations.

4.6 CONCLUSIONS

Improving the aerodynamic efficiency of intermodal freight trains has substantial potential to reduce operating costs and improve energy efficiency. This chapter describes the development of an automated machine vision system for analyzing the loading of intermodal freight trains. This system will allow the BNSF Railway to evaluate the loading of intermodal freight trains along the Transcon from Los Angeles to Chicago. Given the high volume of intermodal traffic along this route, the Sibley, MO installation and machine vision system is capable of analyzing intermodal train loading from multiple intermodal terminals along the corridor. The results will benefit BNSF intermodal terminals, as well as other railroads interested in improving the energy efficiency of their intermodal train operations. If railroads implement improvements to their loading practices, this machine vision system can then serve as a useful measurement tool to track improvements and consequent fuel savings.

CHAPTER 5: TIME-MOTION STUDY OF INTERMODAL TERMINAL PERFORMANCE

5.1 INTRODUCTION AND PURPOSE

The previous chapters provided an overview of intermodal train loading and discussed how optimal loading can reduce operating costs by increasing energy efficiency. However, train loading improvements also have the potential to negatively impact terminal performance, which will be further explored in this chapter. To understand this impact, the gate, lifting, train processes, and dwell times will be studied. Current data describing terminal performance will be used to evaluate how loading and other operational changes affect terminal processes and dwell time. Additionally, this chapter introduces the types of terminal loading data and discusses how it can be used to analyze terminal processes and dwell time by comparing data from multiple terminals.

5.2 TERMINAL LOADING DATA

The data stored in the computer network of an intermodal terminal provides considerable information that can be used to evaluate terminal performance. Terminal loading data provides documentation of the motion of containers and trailers, as well as the equipment that is used for loading and unloading them. Information is stored for each container or trailer at critical points in the terminal process – as it passes in or out of the terminal gate, as it is lifted onto or off of the railcar, and as it arrives or departs by train. The terminal computer network stores data for both outbound and inbound containers and trailers. Outbound data refers to containers or trailers arriving by truck and departing by train. Inbound data refers to containers or trailers arriving by train and departing by truck.

5.2.1 Outbound Data

Outbound containers or trailers arrive at the intermodal terminal through an in-gate or train-load event. An in-gate event occurs when the container or trailer arrives on a truck before departing on a train. The in-gate time is the date and time when the container or trailer enters the terminal through the gate. A train-load event occurs when the container or trailer arrives on one train and departs on another, which could include transferring the container or swapping blocks of railcars.

Typically, each train is identified by its origin and destination. A train and a container or trailer may share the same origin but different destinations because the container or trailer may take part in a train-load event at either end of the route and be loaded on a different train. One Class I railroad identifies their trains with a letter that refers to its train type and a five-digit number whose final two digits refer to the day of departure.

Each container or trailer is identified by a reporting mark and a six-digit number that allows the container or trailer to be tracked within the intermodal network. The reporting mark is a four-letter code signifying the container or trailer's owner. In addition, containers or trailers are classified as "loaded," "empty," or "revenue-empty." The meaning of "loaded" is self evident. An empty container or trailer is one that is owned by the railroad, with no direct revenue generated by transporting it. A "revenue-empty" container or trailer is one that the customer has paid the railroad to transport empty.

Once the outbound containers or trailers have arrived at the terminal, they must be prepared for departure on the train. The lift-on time is the date and time when a container or trailer is lifted onto a railcar. The transfer time is the date and time when the responsibility for a

container or trailer is transferred from the terminal personnel to the railroad transportation personnel. The railroad personnel generate the final train consist and perform outbound mechanical inspections prior to train departure. Dwell time is the amount of time a container or trailer spends at the terminal. Outbound dwell time is the difference between the in-gate time and the transfer time.

5.2.2 Inbound Data

Inbound containers or trailers arrive at the intermodal terminal on a train and depart on a drayage truck. The arrival time is the date and time when the train arrives in the terminal. Like outbound containers or trailers, inbound containers or trailers are identified by mark, number, load status, origin, and destination.

Once the inbound containers or trailers have arrived at the terminal, they must be prepared for customer pick up. This consists of lifting containers and trailers off the train, equipping containers with chassis, and transporting them to the storage area where customers will pick them up. The load availability time is the date and time when the container or trailer arrives at the service track and is available to be lifted off of the railcar. The lift-off time is the date and time at which the lifting crew lifts the container or trailer off of the railcar. The notification time is the date and time when the terminal notifies the customer (typically by e-mail) that the container or trailer is available for pick up. The out-gate time is the date and time when the container or trailer leaves the terminal. Inbound dwell time is the difference between the arrival time and the out-gate time.

5.3 ANALYSIS OF TERMINAL PERFORMANCE

Analysis of inbound and outbound terminal loading data can be used to evaluate terminal performance. The inbound and outbound data were collected for four Class I railroad intermodal terminals, referred to as Terminals A, B, C, and D, in October of 2010. These data allow for the analysis of the gate, lifting, train processes, and inbound and outbound dwell times.

5.3.1 Gate Process

5.3.1.1 In-Gate Time

The in-gate and out-gate times were used to analyze the gate process. General statistics for Terminals A-D, including the number of loads, the mean, the median, the mode, and the standard deviation of load arrival times were calculated to compare terminals (Table 5.1). All four terminals have a mean in-gate time in the early afternoon, and their medians and modes also occur in the early afternoon, with the exception of Terminal C's mode at 09:00. The in-gate time standard deviations are similar, with Terminal A having a slightly higher value.

Table 5.1 Statistics for in-gate times over a one-month period

Statistic		Terminal			
		A	B	C	D
Number of Loads		9,313	9,384	6,269	10,294
In-Gate Time	Mean	12:12	13:36	12:24	12:48
	Median	12	14	13	13
	Mode	12	14	9	13
	Standard Deviation	5.3	4.9	4.8	4.6

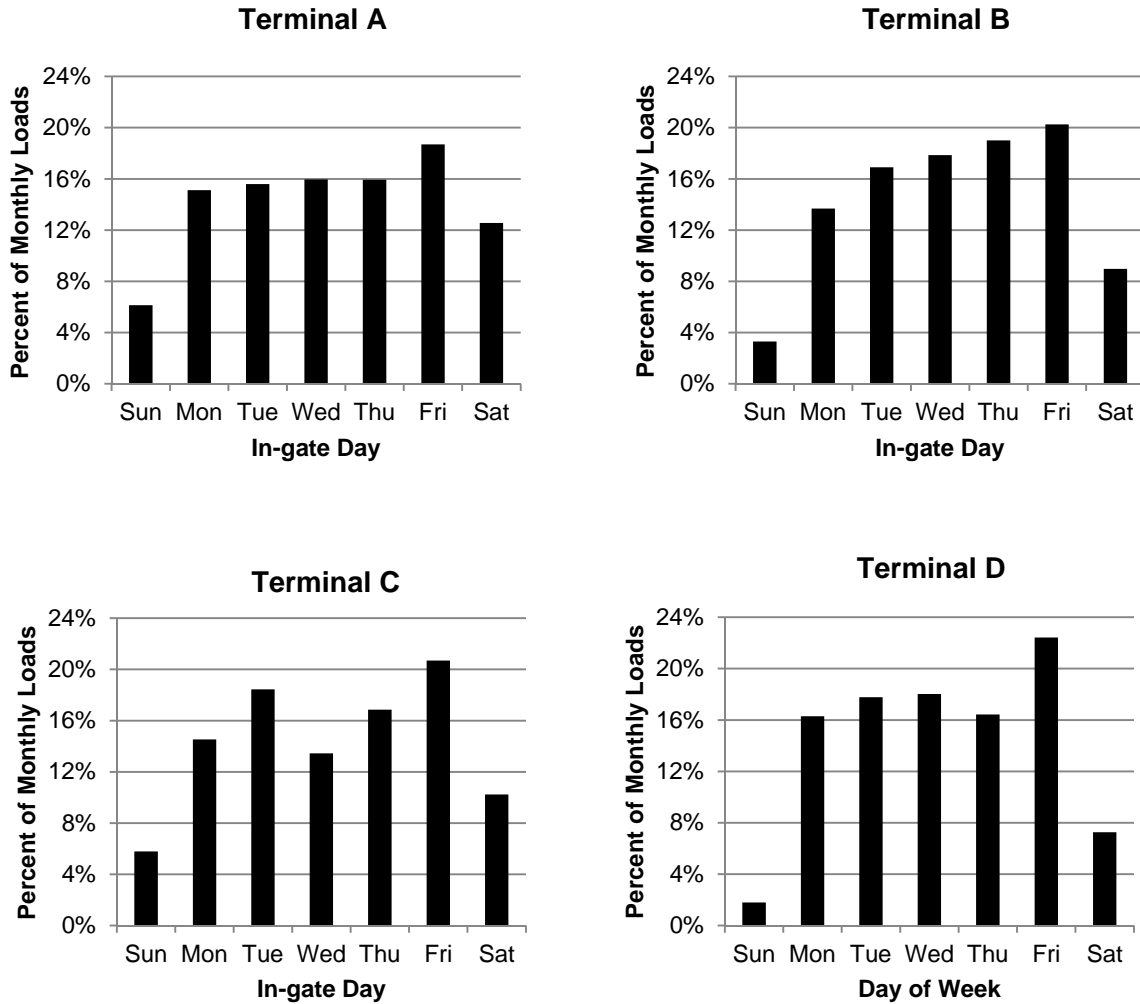


Figure 5.1 In-gate day-of-the-week distributions over a one-month period

The in-gate data were also categorized by the day of week (Figure 5.1) and time of day that container or trailer arrives at the terminal gate. Most of the in-gate times occur during typical business hours, 08:00 to 17:00. The distributions for Terminals A, B, and D resemble a normal distribution, but are skewed away from the middle of the day (12:00). Terminal C's distribution has dual peaks at 10:00 and 15:00.

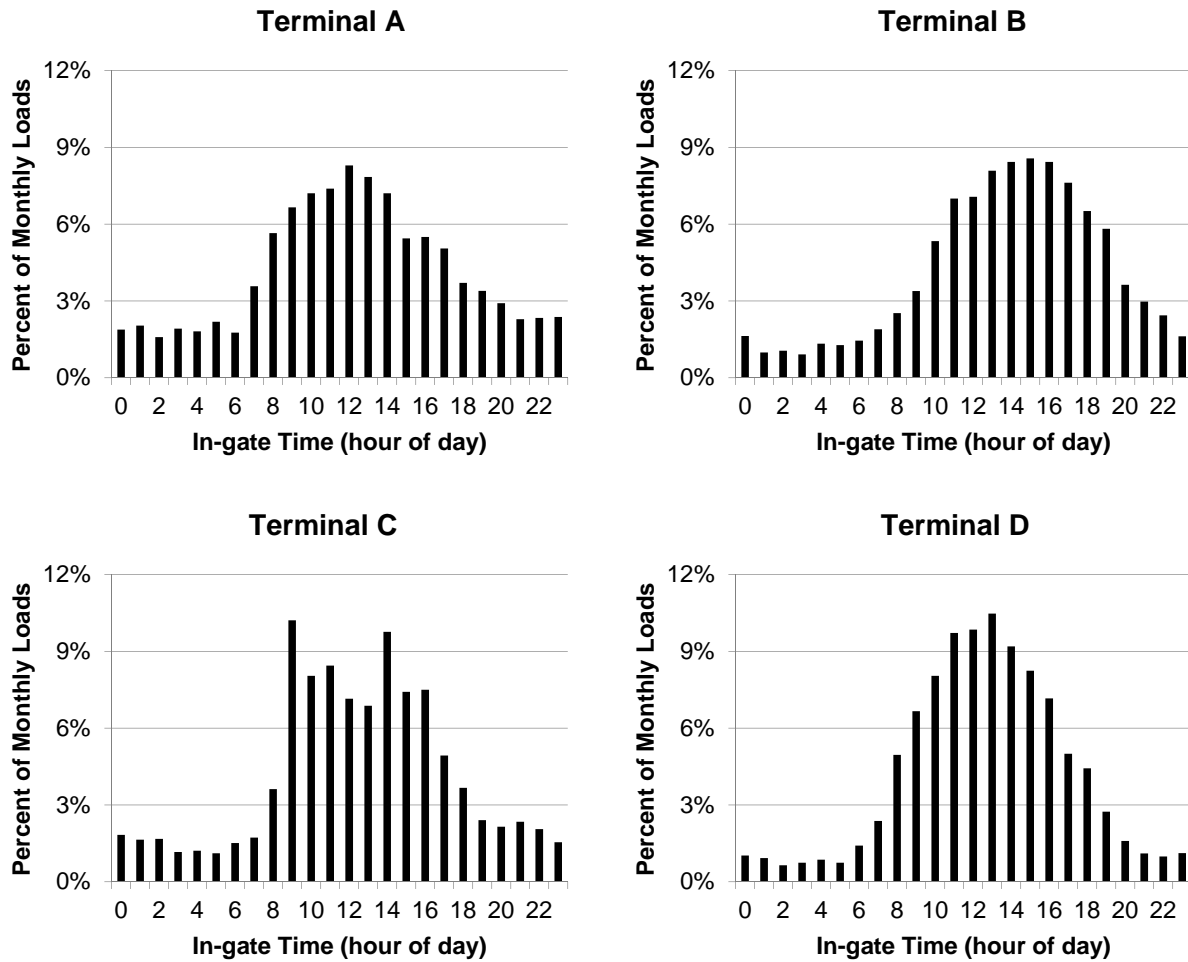


Figure 5.2 In-gate time distributions over a one-month period

5.3.1.2 Out-gate Time

The mean out-gate times for Terminals A, B, and C are very similar, but the mean for Terminal D is approximately one hour earlier (Table 5.2). The medians and modes for the four terminals range from 07:00 to 12:00, which is earlier than the medians and modes for the in-gate times. The average out-gate time is earlier than the average in-gate time because the customers may request that their cargo arrives during business hours. The standard deviations for the out-gate times are slightly higher than the in-gate times. To protect against potential train delays and

ensure that their loads are available upon arrival of the drayage truck at the terminal, customers may pick up their loads well after the loads arrive at the terminal. This practice results in a larger standard deviation in out-gate times compared to in-gate times (Table 5.2).

Table 5.2 Statistics for out-gate times over a one-month period

		Terminal			
Statistic		A	B	C	D
Out-Gate Time	Number of Loads	7,750	11,490	8,112	9,821
	Mean	11:30	11:48	11:42	10:06
	Median	11	12	12	9
	Mode	11	7	12	7
	Standard Deviation	6.0	5.3	4.0	4.7

Similar to the in-gate times, the out-gate times for Terminals A, B, and C are centered in the middle of the day, while those for Terminal D are centered in the morning hours because a large portion of trains arrive at around 05:00 for Terminal D (Figure 5.3). The out-gate day-of-week distributions (Figure 5.4) show the weekends have less traffic than weekends and the peak out-gate traffic occurs earlier in the week.

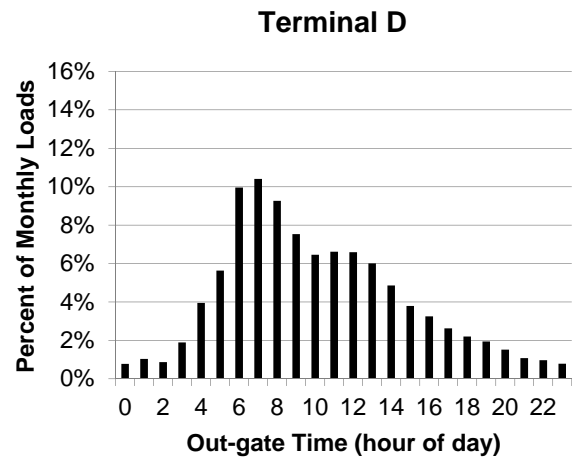
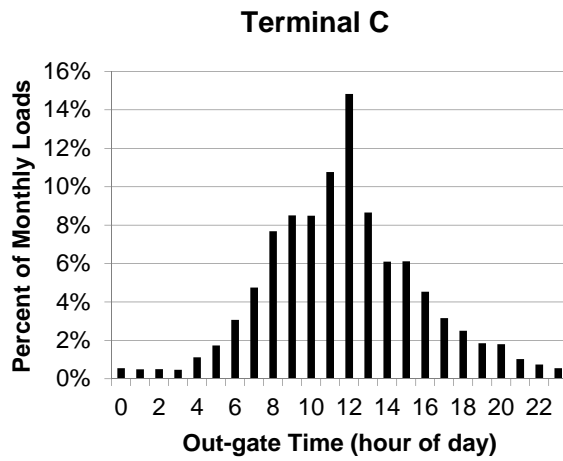
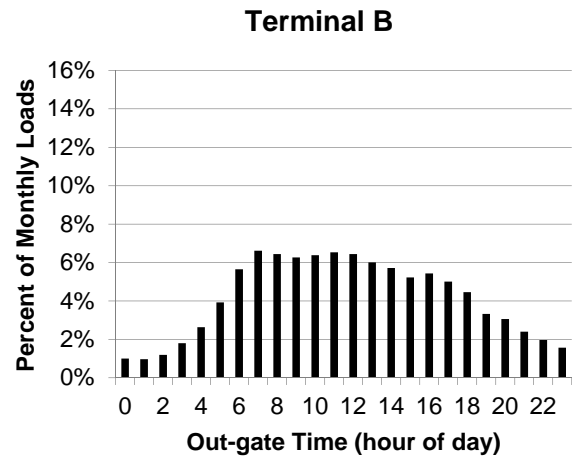
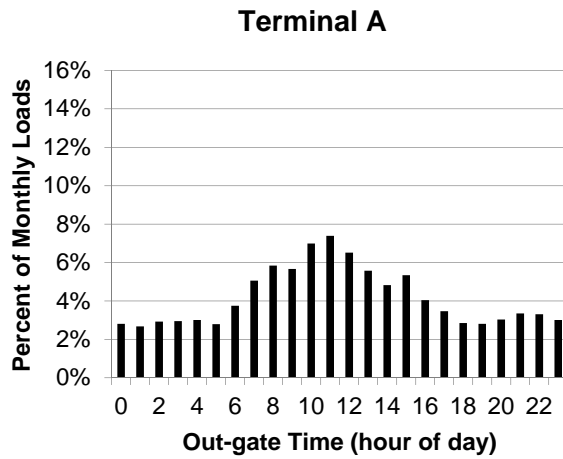


Figure 5.3 Out-gate time distributions over a one-month period

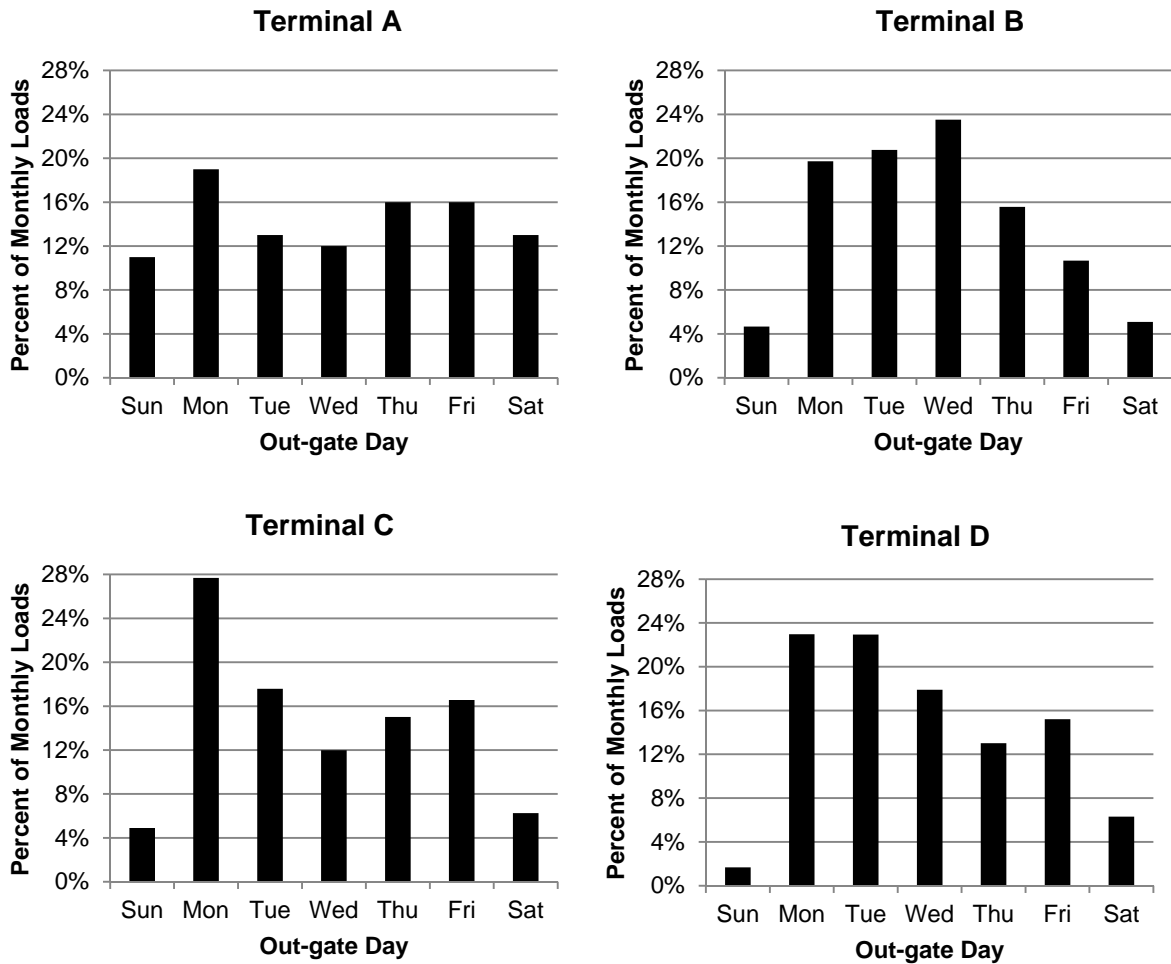


Figure 5.4 Out-gate day-of-week distributions over a one-month period

5.3.1.3 Analysis of Gate Process Data

Analysis of the in-gate and out-gate data shows that the gate traffic flow is not uniform by either day of week or time of day. Uniform traffic flow would be more efficient because facilities could be optimally designed for uniform throughput, minimizing gate congestion (White 2010). To achieve uniform distribution, traffic from peak times and days would need to be diverted to off-peak times and days. Providing customers with incentives to arrive during the off-peak times and days could help, but customer convenience would be sacrificed. Achieving

uniform distribution is also dependent on rolling stock and locomotive availability and can affect terminal storage capacity and efficiency, potentially causing congestion.

5.3.2 Lifting Process

5.3.2.1 Lift-on Time

The lift-on times and lift-off times were used to analyze the lifting process, which occurs between the gate and train processes (Table 5.3). Each terminal has a different mean lift-on time, ranging from the late morning to the afternoon. The large standard deviation values for the mean lift-on time is due to the variation in train departure times and the availability of the lifting equipment. The lift-on median and mode times range from the early afternoon to evening, showing that a majority of the lift-on activity occurs later in the day.

Table 5.3 Statistics for lift-on times over a one-month period

Statistic		Terminal			
		A	B	C	D
Number of Loads		9,313	9,384	6,269	10,294
Mean Time		11:00	13:36	12:36	15:07
Lift-on Times	Median	12	16	13	17
	Mode	15	19	13	22
	Standard Deviation	6.7	7.2	5.6	7.8

In the lift-on time distributions (Figure 5.5), it is evident that a majority of lift-on activity occurs before or after normal business hours (08:00 to 17:00) with the exception of Terminal C where approximately 40% of the lift-on activity occurs after normal business hours.

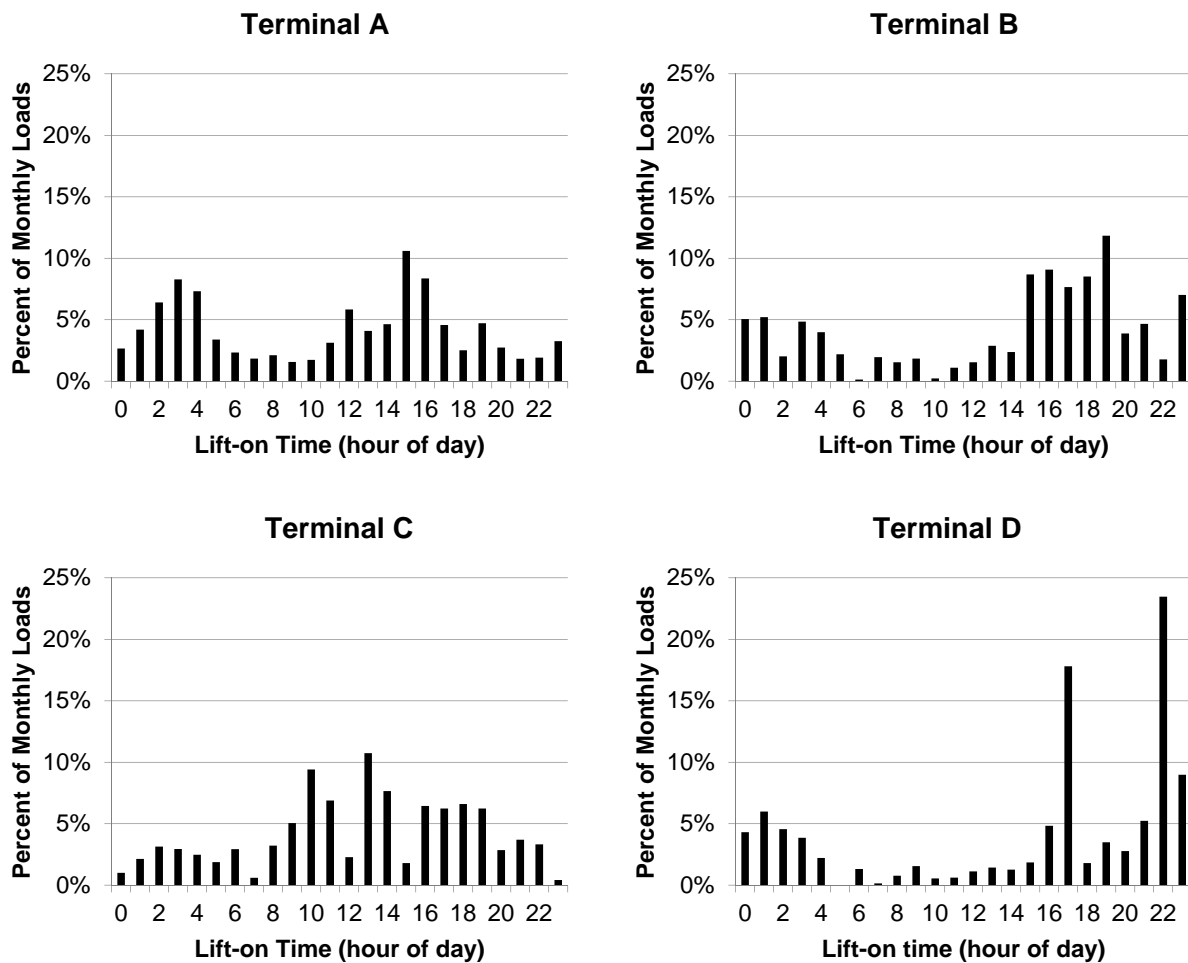


Figure 5.5 Lift-on time distributions over a one-month period

5.3.2.2 Lift-off Time

The mean lift-off time (Table 5.4) varies from mid-morning to early afternoon, and the range in standard deviation is similar to the range for lift-on times. Notice that the mean,

median, and mode for lift-off time values typically occur before the respective lift-on times. The earlier lift-off times may occur when terminals are preparing the loads for customer pick up during normal business hours. The early mean out-gate times show that customers typically pick up their loads from terminals early in the day.

Table 5.4 Statistics for lift-off times over a one-month period

		Terminal			
Statistic		A	B	C	D
Lift-off Times	Number of Loads	7,750	11,490	8,112	9,821
	Mean	10:24	9:54	12:12	11:30
	Median	10	9	11	12
	Mode	10	11	8	14
	Standard Deviation	7.2	6.4	6.5	5.4

The lift-off times are more evenly distributed (Figure 5.6) than the lift-on times due to the higher variability of train arrivals than train departures caused by mainline delays resulting from capacity constraints and/or infrastructure maintenance activity. The peak lift-off times are also less distinct than the peak lift-on times.

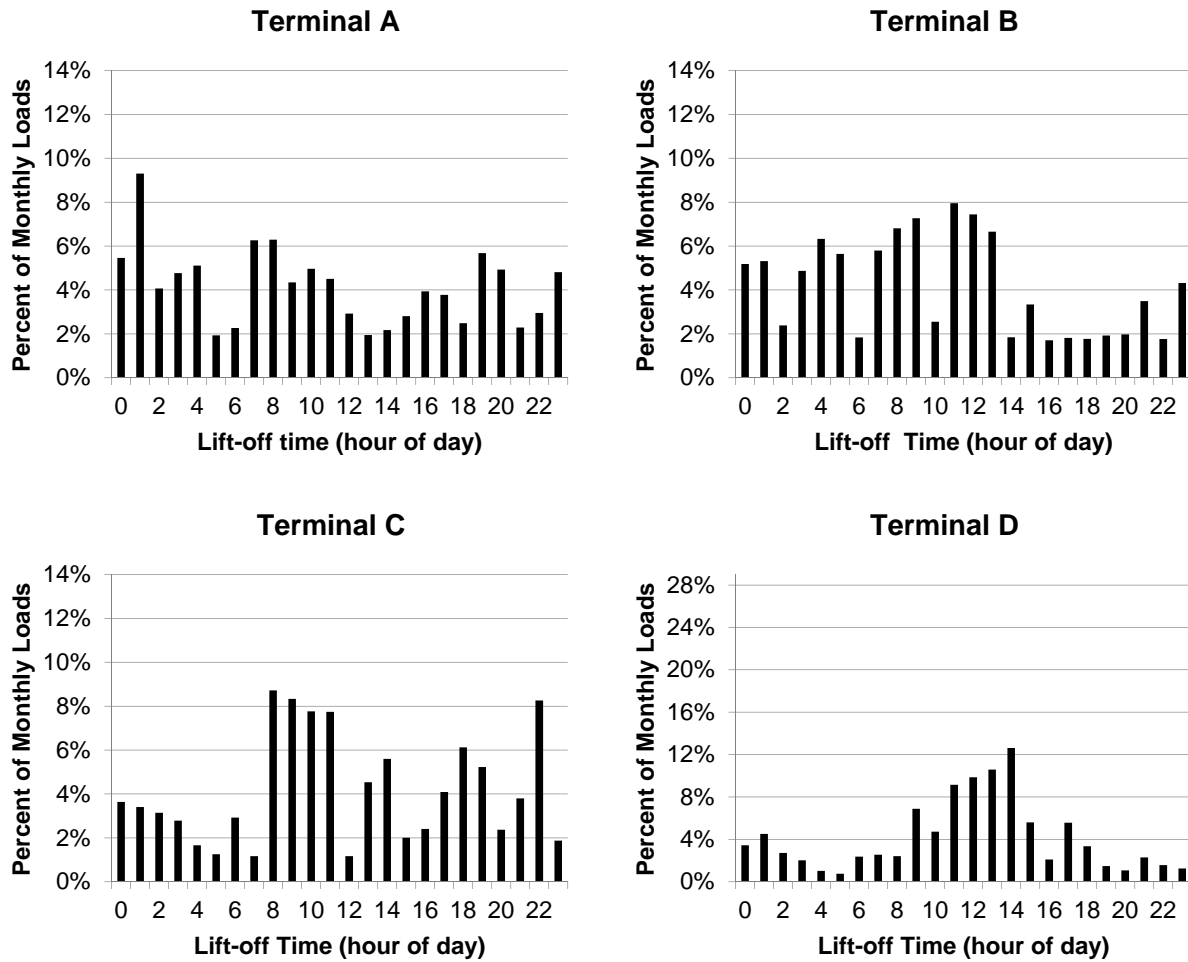


Figure 5.6 Lift-off time distributions over a one-month period

5.3.2.3 Analysis of Lifting Process Data

Analysis of the lift-on and lift-off time data shows that the volume of containers and trailers lifted is not constant. As with gate traffic, more uniform lifting activity would improve efficiency and improve lifting equipment utilization rates. However, lifting activity is dependent on the arrival time of drayage trucks, train schedules, and availability of the lifting equipment. More consistent lifting activity could be achieved by coordinating train departure times and arrival times based on the availability of the lifting equipment all of which are stochastic

processes. However, consistent lifting activity may be cost-ineffective because train operating costs are higher than lifting equipment operations and scheduling conflicts may negatively affect other terminals within the network.

5.3.3 Train Process

5.3.3.1 Transfer Times

Transfer and arrival times were used to analyze when trains depart and arrive at terminals, respectively (Table 5.5). The mean transfer times for the four terminals, which range from the early to middle afternoon, occur on or after the mean lift-on times. The standard deviations for the four terminals range from five to almost eight hours compared to the respective mean transfer times. Also, the median and mode for transfer times for each terminal occur later than the respective median and mode lift-on times. This reflects the fact that the release time for a load occurs shortly after the load is lifted onto the train.

Table 5.5 Statistics for transfer times over a one-month period

		Terminal			
Statistic		A	B	C	D
Number of Loads		9,313	9,384	6,269	10,294
Transfer Times	Mean	12:12	14:36	14:42	15:12
	Median	12	19	14	17
	Mode	12	19	14	22
	Standard Deviation	5.4	6.8	5.3	7.8

The peak transfer times for all four terminals occur between the late morning and the early afternoon (Figure 5.7). The large peak values show the correlation of transfer times with train departures. For example, 84% of Terminal A's monthly loads have a transfer time at 05:00, 15:00, and 17:00. The hours with smaller percentages represent transfer times corresponding to delayed trains and/or containers or trailers that are early or late relative to the time they need to be checked in to meet a scheduled train departure time (cut-off time).

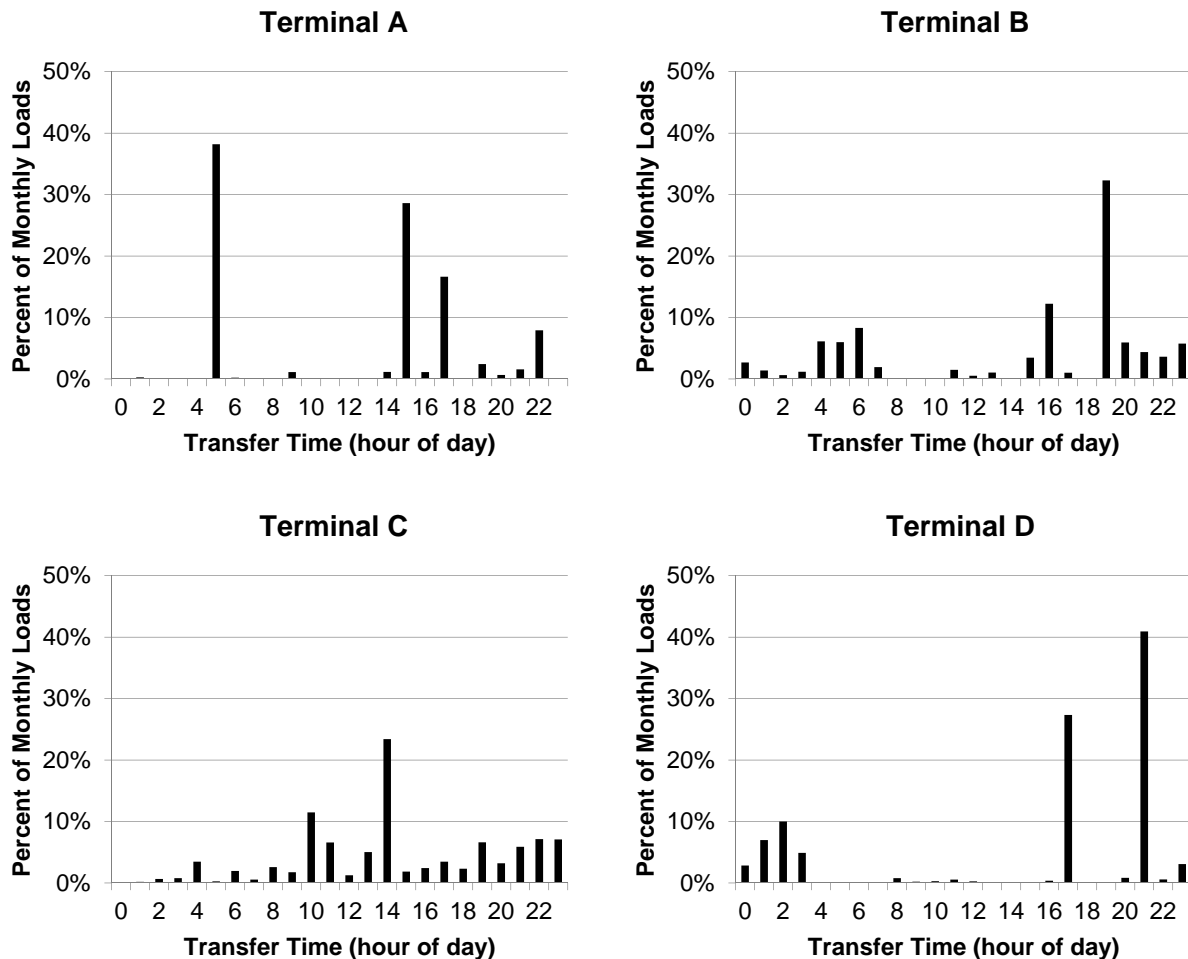


Figure 5.7 Transfer time distributions over a one-month period

5.3.3.2 Arrival Time

The arrival time statistics for Terminals A-D are provided in Table 5.6. The mean arrival time is different for each terminal because trains arrive at different times. The mean, median, and mode arrival times generally occur earlier in the day compared to the transfer times. The exception is Terminal A, which occurs later. The median and mode arrival times have a larger range than the mean times, especially the mode where it ranges from 05:00 to 22:00. The standard deviations of the arrival times are slightly larger than the standard deviations of the transfer times (Table 5.5), except for Terminal D.

Table 5.6 Statistics for the arrival time over a one-month period

		Terminal			
Statistic		A	B	C	D
Number of Loads		7,750	11,490	8,112	9,821
Arrival Time	Mean	13:30	8:12	12:24	9:36
	Median	15	7	12	8
	Mode	22	5	17	8
	Standard Deviation	7.1	6.4	5.5	5.6

The arrival time distributions are also different for each terminal (Figure 5.8). Terminal A's arrival time distribution is more uniform while Terminal D's is more concentrated in the morning hours. The arrival time distributions do not resemble those for transfer times because of the larger variation in train arrival times than train departure times. Train arrival times vary due to mainline delays resulting from capacity constraints and/or infrastructure maintenance activity.

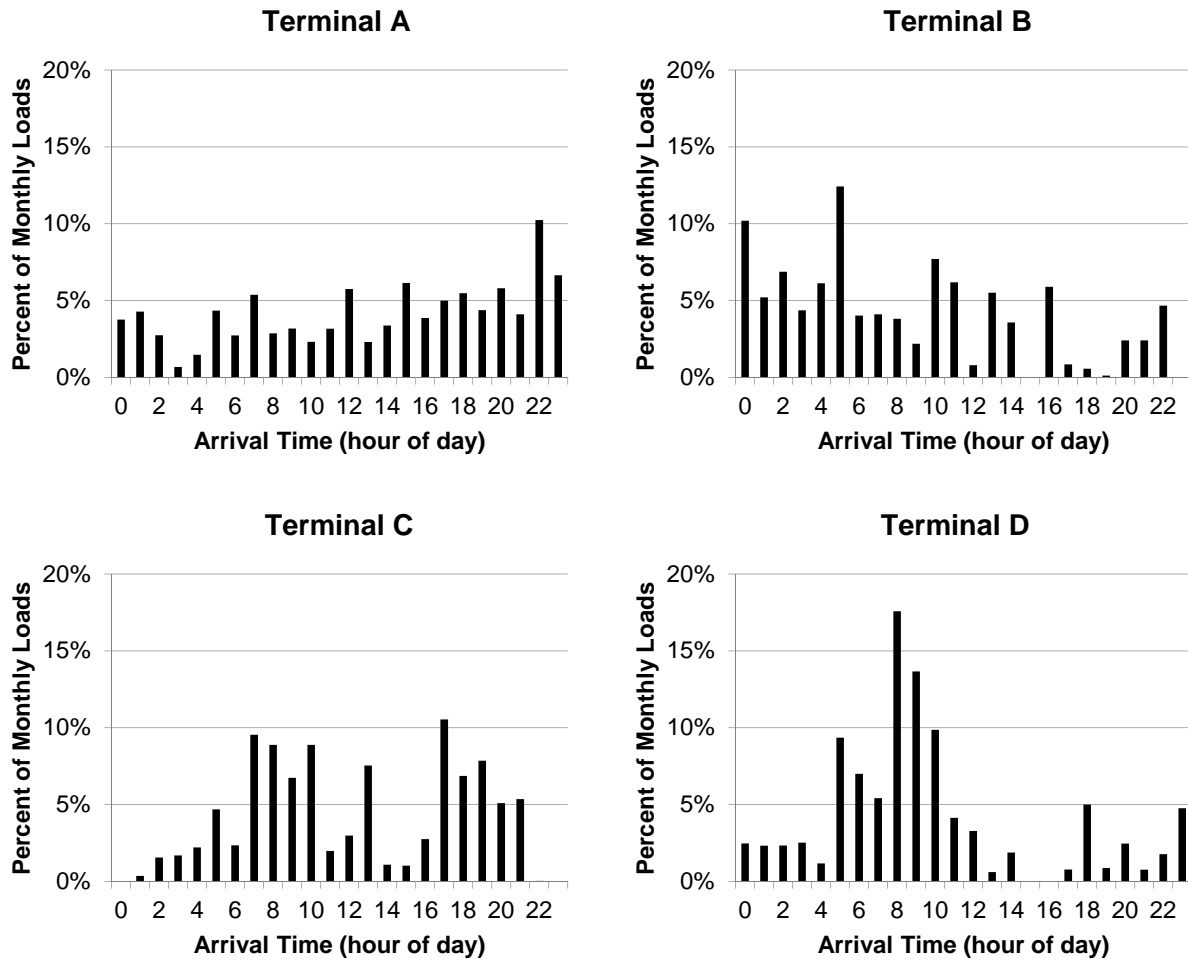


Figure 5.8 Arrival time distributions over a one-month period

5.3.3.3 Analysis of Train Process Data

Analysis of the arrival and transfer time data shows that the train processes are not uniform but are concentrated in specific time intervals corresponding to train arrival and departure times. Uniform train activity, achieved by evenly distributing train arrival and departure times throughout all hours of the day, would result in greater operational efficiencies by achieving higher utilization of the lifting equipment and strip tracks. However, forcing an

even distribution may adversely affect scheduling (network) efficiency and customer requirements. Train process efficiency may be better achieved by improving train punctuality. Coordination with the lifting crews and stricter enforcement of the cut-off time would improve on-time performance. Also, more efficient and accurate outbound inspections using technologies such as machine vision could help minimize departure delays and reduce mechanically-caused derailments on the mainline.

5.3.4 Dwell Time

5.3.4.1 Outbound Dwell Time

Outbound and inbound dwell times are used to analyze terminal performance. The mean, the standard deviation, the median, and the range of outbound dwell times for Terminals A-D are provided in Table 5.7. Over half of the containers and trailers have a dwell time of 24 hours or less. Tables 5.8, 5.9, and 5.10 organize the dwell time statistics by container or trailer type: empty, revenue-empty, or loaded. Empty containers or trailers typically have a significantly longer dwell time than loaded containers or trailers. Terminal C has the lowest mean dwell time, but it also has the smallest sample size and standard deviation (Figure 5.9). Terminal B has the highest mean dwell time due to the high mean dwell times of empty and revenue-empty containers or trailers. However, Terminal B has the second lowest mean dwell time for non-empty loads. Terminal A has the second lowest mean dwell time due to the low mean dwell time for empty containers or trailers. But, Terminal A has the highest mean dwell time for revenue-empty and loaded containers or trailers.

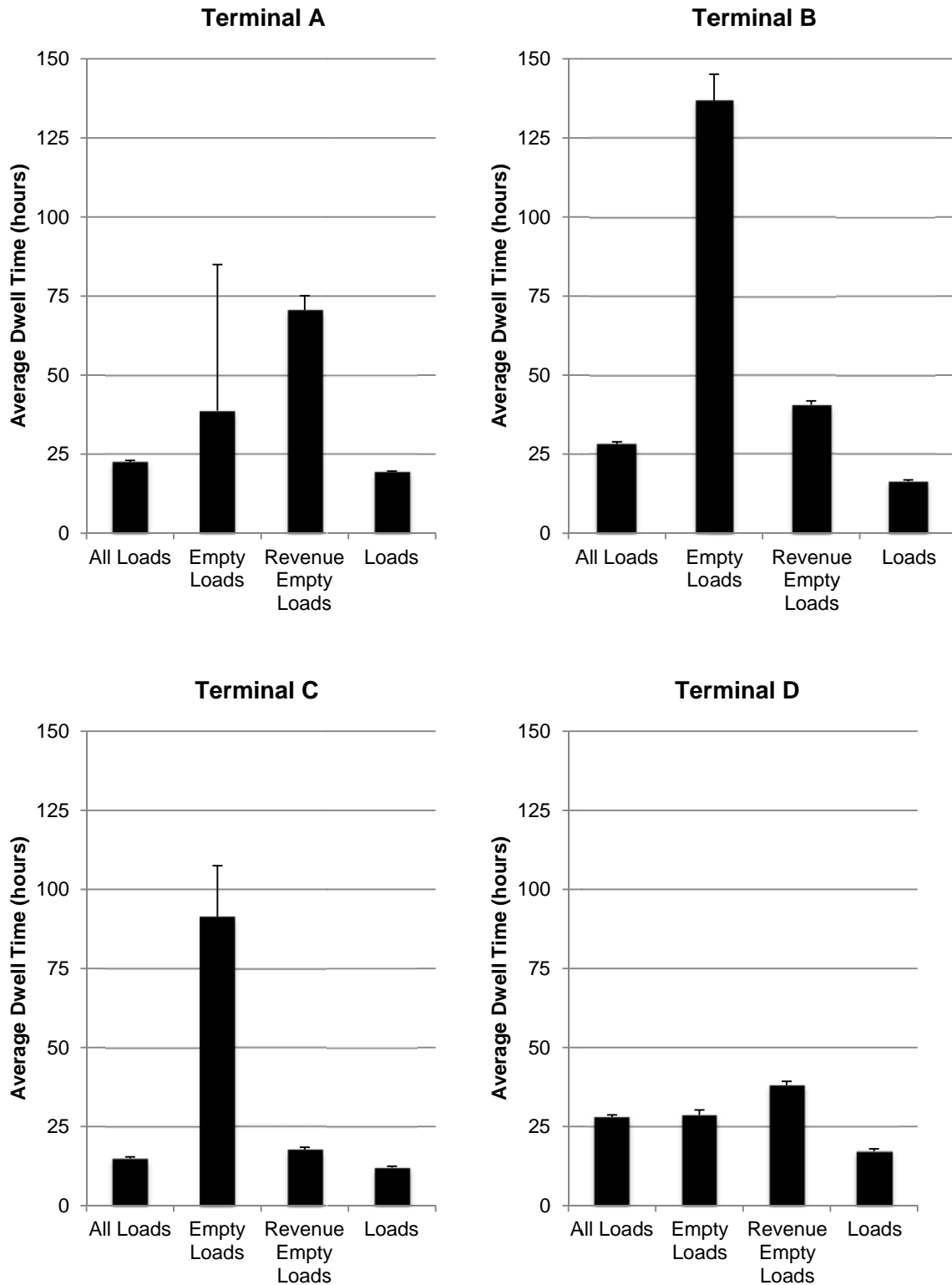


Figure 5.9 Average outbound dwell time for various load types over a one-month period. Error bars indicate two standard errors

Table 5.7 Dwell time statistics for all outbound load types over a one-month period

		Terminal			
Description		A	B	C	D
Number		9,313	9,389	6,271	10,294
Outbound Dwell Time (All Load Types)	Mean	22:31	28:11	14:52	27:58
	Standard Deviation	24.82	34.38	20.98	35.25
	Median	18:24	18:12	10:06	16:24
	Range	615:48	409:12	629:18	604:36
	Percent having a dwell time of 24 hours or less	70%	63%	84%	59%

Table 5.8 Dwell time statistics for outbound empty containers or trailers over a one-month period

		Terminal			
Statistic		A	B	C	D
Number		11	222	102	2,247
Outbound Dwell Time (Empty Containers or Trailers)	Mean	38:42	136:48	91:18	28:36
	Standard Deviation	76:42	62:12	81:48	39:30
	Range	259:36	377:48	336:54	563:36

Table 5.9 Dwell time statistics for outbound revenue-empty containers or trailers over a one-month period

		Terminal			
Statistic		A	B	C	D
Number		580	3,469	1,697	4,058
Outbound Dwell Time (Revenue Empty Containers or Trailers)	Mean	70:36	40:36	17:42	38:06
	Standard Deviation	54.4	36.8	15.9	39.0
	Range	373:54	308:54	176:48	566:00

Table 5.10 Dwell time statistics for outbound loaded containers or trailers over a one-month period

		Terminal			
Statistic		A	B	C	D
Number		8,720	5,693	4,470	3,989
Outbound Dwell Time (Loaded Containers or Trailers)	Mean	19:18	16:23	12:00	17:12
	Standard Deviation	17	16.7	15.0	23.6
	Range	615:48	409:06	629:18	603:54

Outbound dwell times for Terminals A-D are also graphically represented as time distributions and cumulative distribution curves (Figure 5.10). The majority of the outbound dwell times range from zero to 30 hours and there is a small proportion of dwell times that are greater than 100 hours, namely for Terminals B and D.

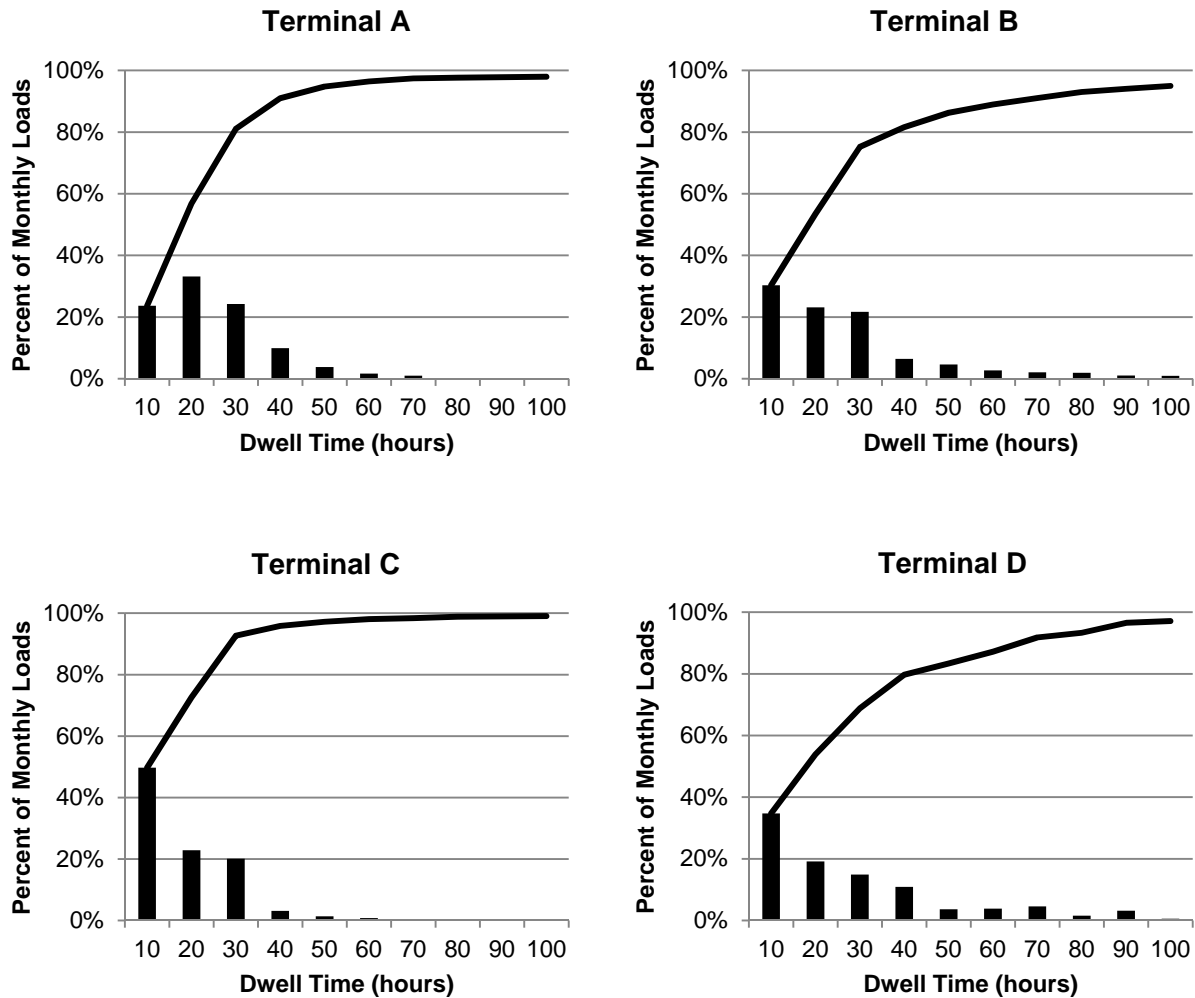


Figure 5.10 Outbound load dwell time frequency and cumulative distributions over a one-month period

5.3.4.2 Inbound Dwell Time

The mean inbound load dwell times (Table 5.11) range from over one day to just less than two days, which are larger than the outbound dwell times. The median dwell time values are smaller than the mean value so the data are skewed towards smaller dwell time values. Terminal B had the smallest standard deviation of about 29 hours and Terminal D had the largest at about 34 hours and largest range of 487 hours (Figure 5.11). It is interesting to note that Terminal A has the smallest inbound volume and average dwell time but the second largest

standard deviation and range. This difference may be due to the terminal's lack of stricter demurrage fees that may discourage longer dwell times. However, a smaller terminal with sufficient storage capacity may not need strict demurrage fees such as larger terminals that are capacity constrained.

Inbound data for the four terminals were divided only by loaded containers and trailers and revenue empties and the data did not contain any empty containers or trailers. The mean dwell times for revenue empty containers and trailers (Table 5.12) are higher than the total average dwell time, except for Terminal D. The standard deviations of the revenue empties are also typically higher than the total standard deviation. The loaded containers and trailers (Table 5.13) are more numerous than revenue empties. Because the majority of the containers and trailers handled by the four terminals are loads, the mean ranges, and standard deviations are similar to the total mean, range, and standard deviation dwell times, except for Terminal A that has a large number of revenue empties in the month studied.

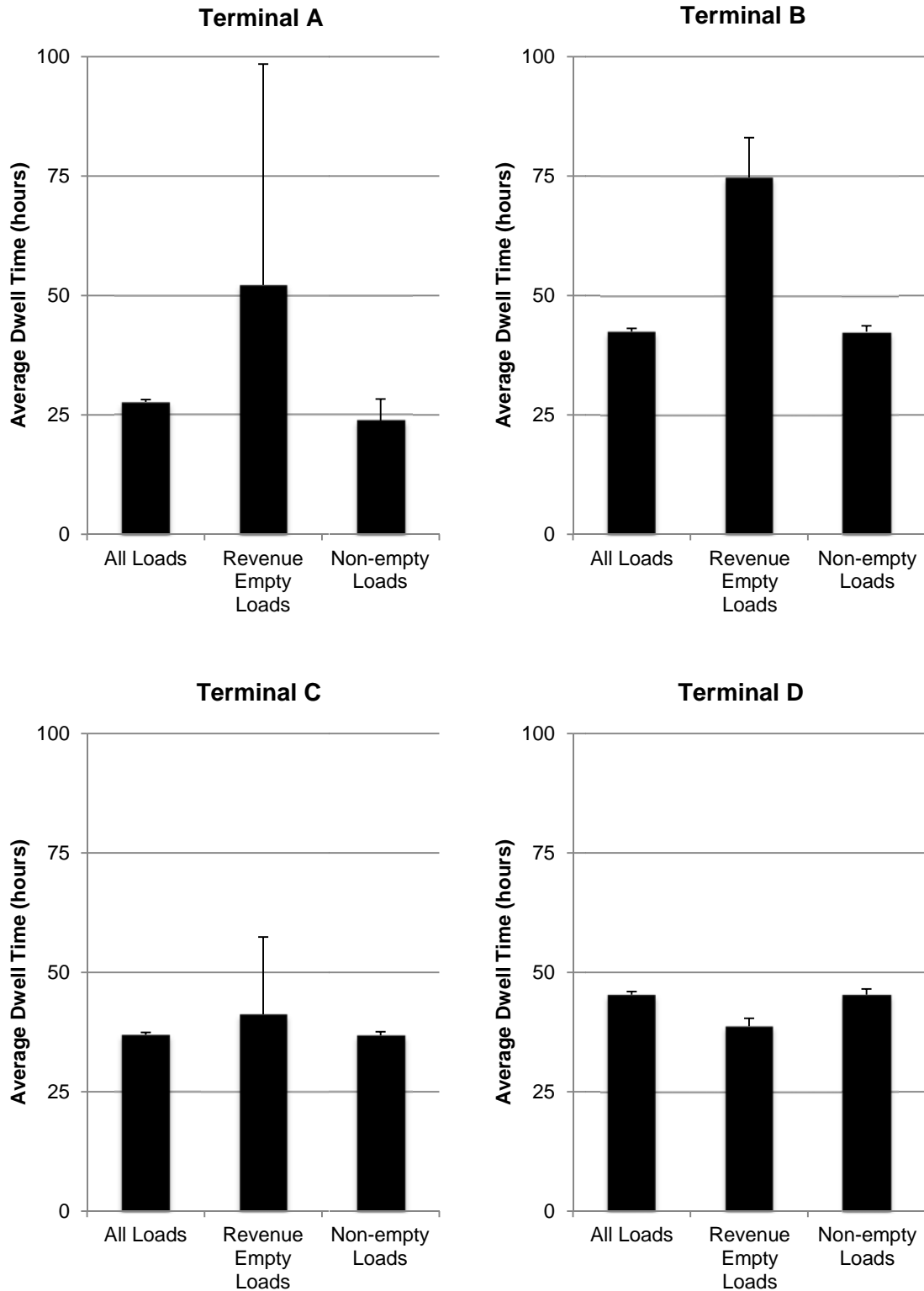


Figure 5.11 Average inbound dwell time for various load types over a one-month period. Error bars indicate two standard errors

Table 5.11 Dwell time statistics for all inbound load types over a one-month period

Statistic	Terminal			
	A	B	C	D
Number	7,549	11,490	8,112	9,821
Mean	27:43	42:22	36:55	45:18
Standard Deviation	32.03	28.65	31.28	33.86
Median	16:42	35:00	27:45	36:00
Range	472:30	375:48	303:30	486:48
Percent having a dwell time of 24 hours or less	67%	31%	43%	32%

Table 5.12 Dwell time statistics for inbound revenue-empty containers or trailers over a one-month period

Statistic	Terminal			
	A	B	C	D
Number of Loads	1,031	4	202	5
Mean	52:12	74:42	41:12	38:42
Standard Deviation	54.5	10.8	25.1	19.8
Range	412:42	22:24	138:00	49:06

Table 5.13 Dwell time statistics for inbound loaded containers or trailers over a one-month period

		Terminal			
Statistic		A	B	C	D
Number		6,518	11,486	7,910	9,816
Inbound Dwell Time (Loaded Containers or Trailers)	Mean	23:48	42:24	36:48	45:18
	Standard Deviation	24.6	28.6	31.4	33.9
	Range	472:30	375:48	303:36	486:48

Figure 5.12 shows the inbound dwell time frequency and cumulative distributions for Terminals A-D. The inbound dwell times are longer than outbound dwell times because customer preference determines when loads will be retrieved. Some loads are retrieved promptly and others remain in the terminal for several days. A customer may choose to pick up their load two days after the scheduled arrival time to minimize the risk of arrival delay. If the load arrives early, the customer may not be ready to receive it. Customers may have contractual arrangements that permit them to store loads at the terminal for a specified number of days before incurring demurrage fees.

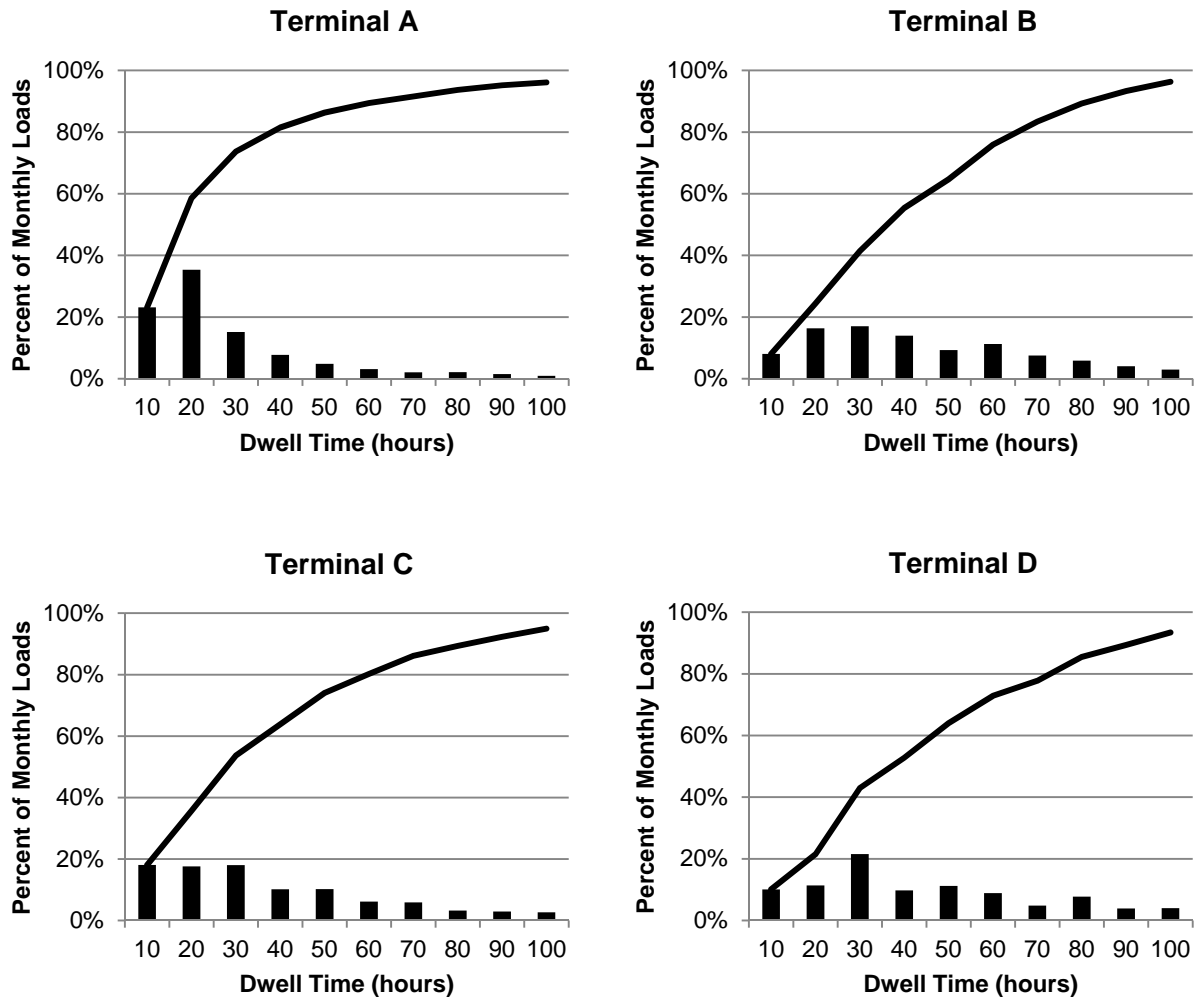


Figure 5.12 Inbound dwell time frequency and cumulative distributions over a one-month period

5.3.4.3 Analysis of Dwell Time Data

Analysis of the inbound and outbound data shows that dwell times are not uniform but vary by the type of container or trailer. The outbound load dwell times tend to have a left-skewed distribution around the shorter dwell time intervals from 0 to 30 hours, while the inbound dwell times are more evenly distributed over a larger range. For the outbound load types, loaded containers and trailers had the shortest dwell times that were less than the average and empty

loads had the longest dwell time. Inbound loaded container and trailer dwell times had the shortest dwell time of all load types except for Terminal D where the revenue empties were shortest.

Dwell time variation can impact storage availability and increase dwell time for other load types. More uniform dwell time would be more efficient and could be achieved by stricter demurrage fees and other incentives for customers to pick up their loads sooner. However, customers may prefer to not pick up their loads immediately after the train's scheduled arrival because they have an allotted extra time buffer into their drayage schedule to minimize the risk of arriving at the terminal to pick up the load only to find that it has not arrived yet. As railroads improve the reliability of intermodal-train arrivals, customers may choose reduce these buffer times and pick loads up as soon as they are available.

5.4 LIMITATIONS OF TERMINAL LOADING DATA

The analysis of loading data provides a useful tool to evaluate terminal performance. It provides information on the major components of the intermodal processes by quantifying certain parameters regarding the motion of containers and trailers within the terminal. However, terminal loading data has some limitations and thus does not provide a complete understanding of terminal performance.

For outbound data, the in-gate time documents the arrival of outbound containers or trailers but does not account for the time containers or trailers wait outside the gate. The outbound dwell time documents the total time a container or trailer spends in the terminal but does not provide more detailed information about what occurs between the in-gate and lift-on times. During those times, the container or trailer could have been parked in storage and later

retrieved by lifting equipment, but the occurrence and times of those events are not recorded.

Also, the dwell time metric does not document when work orders for lifting containers or trailers are created by terminal personnel. The large spikes in transfer times maybe due to lifting crews waiting until they have time to complete the loading information rather than the actual time the event occurred. For example, it is possible that some of the lifts that are recorded as occurring at a peak time such as 17:00 actually occurred prior to the apparent peak hour (such as 16:00) and the recorded hour is incorrect. Verification of the transfer time values would help determine whether transfer times truly occur at these peak hours.

For the inbound data, dwell time documents the total time a container or trailer spends in the terminal but does not provide information about what occurs between the notification and the out-gate times. During those times, the drayage truck arrives at the gate and the container or trailer is retrieved from storage, but the times of those events are not recorded.

5.5 CONCLUSION

Evaluation of terminal performance is a relevant topic for study because terminal capacity constraints will become more prevalent as intermodal traffic grows. Terminal loading data can be used to evaluate and predict terminal performance. For example, railroads can use terminal loading data to identify where bottlenecks occur in terminals and measure how terminal reconfigurations and upgrades improve terminal performance. The loading data collected from Terminals A-D provided insight into the gate processes, the lifting processes, the train processes, and the dwell time. Analysis of the data showed that neither the processes nor the dwell times are uniform, thereby reducing efficiency. Improvements, such as diverting drayage traffic to off-peak times and more evenly distributed train arrival and departure times, can affect other aspects

of terminal operation such as storage availability. Additionally, terminal loading data could be used to conduct before and after studies to assess the effect of operational improvements on terminal performance.

CHAPTER 6: CONCLUSIONS AND FUTURE RESEARCH

6.1 CONCLUSIONS

An objective of this thesis was to consider how train loading practices could be improved to increase the fuel efficiency of intermodal freight train operation. Since modification of intermodal train loading practices will affect terminal practices, I also reviewed terminal operations and studied the performance of terminal processes using terminal loading data. The following sections provide an overview of the conclusions and future research associated with the primary topics of this thesis.

6.1.1 Analyzing Intermodal Train Loading and Aerodynamic Efficiency Using Loading Metrics and Machine Vision Technology

The principal focus of this thesis was to develop methods for evaluating intermodal train loading practices and their relationship to energy efficient operations. In Chapter 3, three loading metrics were presented and compared. Several loading configurations were scored using these three metrics to show how each one uniquely evaluates train loading and aerodynamics. The slot efficiency metric provided the most comprehensive evaluation of loading configurations by accounting for both slot length and load size. The use of the slot efficiency metric could help railroads build more energy-efficient train consists that minimize the gap length between loads. However, the modifications in loading practices required to achieve this could impose constraints on terminal operations by restricting load and rolling stock availability, increasing dwell time, and impairing customer service. Further analysis should be undertaken to determine the cost effectiveness of various approaches to modifying loading practices to improve train aerodynamics.

In Chapter 4, I discuss how the aerodynamics and the loading efficiency of intermodal trains can also be evaluated using machine vision technology. In this machine vision system, wayside detectors send a signal to the system that a train is approaching and initiate the operations of other sub-systems. Videos of trains passing the site are captured and stored on a computer. Next, machine vision algorithms analyze the train loading configurations to identify the width of gaps between loads. The gap data gathered from the field site were then inputted into a computer program developed at UIUC that evaluates the train's loading configuration using its average slot efficiency score and its aerodynamic coefficient. Once the system is fully operational, results will be sent to the appropriate railroad offices, where they will be used to evaluate and improve train loading and energy efficiency. The machine vision system demonstrates the feasibility of using this technology for evaluating train loading practices.

6.1.2 Evaluating the Efficiency of Intermodal Terminal Processes using Performance Metrics and Terminal Loading Data

To better understand intermodal train loading practices, I studied intermodal terminal operations and performance. In Chapter 2, key aspects of terminal operations are described, including terminal layout and rail, drayage, and lifting operations. These operations were evaluated using a variety of intermodal performance metrics, including financial, safety, customer service, lifting equipment, storage, and drayage performance. These metrics are interdependent, illustrating the complexity of intermodal terminal operations, and anticipate the pervasive consequences of altering train-loading procedures.

Terminal performance can be further evaluated using terminal loading data. In Chapter 5, I described the types of loading data that intermodal terminals collect to monitor the movement of containers and trailers. Data from four intermodal terminals were analyzed to

evaluate the efficiency of the terminal gate, lifting, and train processes and to calculate load dwell time. Overall, the use of terminal loading data in this preliminary analysis demonstrated its ability to quantify terminal productivity and the potential to quantify how operational modifications (e.g., purchasing new lifting equipment and automated gates) affect terminal performance.

6.2 FUTURE WORK

6.2.1 Economic Analysis of Intermodal Train Energy Efficiency Improvements

The research described in this thesis suggests related areas where further study would be beneficial. Prior to implementing loading practice modifications, a detailed study comparing the costs and benefits of possible strategies to improve intermodal train energy efficiency is needed. Strategies considered in this study would include redesigning (optimizing) rolling stock, intermodal containers and trailers, adding aerodynamic attachments to railcars, reducing train speed, and implementing more aerodynamic intermodal train loading practices such as those considered in this study. Factors such as the cost of retrofitting and/or manufacturing new railcars, the problems associated with new container and trailer designs, the service life of retrofitted equipment and/or attachments, and the train delay costs associated with improved loading should be evaluated. Studying improved loading practices should also include quantification of costs associated with filling empty slots with empty containers/trailers, as discussed in Lai and Barkan (2005).

6.2.2 Terminal Capacity

The study of intermodal terminal performance conducted in this thesis could be expanded to study how to cost-effectively increase the capacity of existing intermodal terminals through operational improvements. To maintain or improve current levels of service performance and increase intermodal market share, railroads are upgrading existing terminals and constructing new ones throughout the U.S to meet the growing demand of intermodal freight service. In addition to physical expansion of terminal facilities, it may also be possible to increase their capacity through more efficient use of the facility. Terminal capacity can be assessed by studying the effect of train schedules, facility design, and equipment availability on various metrics of terminal performance. This question lends itself to a parametric analysis considering the variables above that would provide data on the sensitivity of specific operational changes on overall terminal performance. Previous research has been conducted on terminal optimization and simulation models to determine how various elements affect performance and capacity. This research should continue as existing terminals are retrofitted and new ones constructed. The long-term objective is to better understand the combination of facility expansion and operational improvements that optimizes the balance between cost and service quality for intermodal transport.

6.2.3 Lean Improvements

Terminal loading data, which I considered briefly in this thesis, could be used to measure and reduce service variability. The freight rail industry has an ongoing objective to increase service quality while reducing costs. To accomplish these seemingly conflicting goals, the

application of lean manufacturing techniques should be further researched. Activities to consider in a lean study include gate, lifting, and train operations; administrative activity (paperwork and billing); and information flows. Lean theory would classify these activities into the following categories (Marlow and Paixão 2003):

1. Adding value
2. Not adding value but necessary for the fulfillment of activities in the first category
3. No value added

The costs for activities in the third category (e.g. accidents, injury, unnecessary motion, etc.) would need to be removed from the system to minimize operating costs and increase service quality. In addition to removing these activities, lean manufacturing methods would seek to minimize service variability for the customer, a frequent source of complaints from rail shippers. Terminal loading data could be used to measure the variations in the service offered at each stage of the intermodal transportation process. Research could also be conducted to determine the causes of variability in these processes, explore methods to reduce it, and measure the impact of improvements.

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